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Research in NOAA: Toward Understanding and Predicting Earth's Environment

A Five-Year Plan: Fiscal Years 2007 - 2011

June 2007

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Preface

Recognizing that research is the foundation for an innovative and productive society, NOAA has taken several steps in the past few years to maximize the benefit of its research. In 2005, NOAA released its first agency-wide research plan, describing an interdisciplinary and coordinated approach to the research needed to support its mission for fiscal years 2005-2009. Production of the research plan was overseen by the NOAA Research Council, a committee of senior scientists from NOAA's line offices and mission goals. In 2005, the Research Council also produced a 20-year "Research Vision" to provide overarching direction for the agency's research based on its perspective of the environmental challenges likely to face the nation in the decades ahead. The vision document recognizes NOAA's fundamental role in supporting policy and decision makers in addressing those challenges, and the current 5-year plan gives voice to the research needed now to meet society's needs.

The ensuing two years have seen considerable progress in achieving the milestones set out in the original plan, as we continue to adjust NOAA's science and infrastructure to better meet the increasingly complex environmental and socioeconomic challenges of the 21st century. The past two years have also seen new environmental issues emerge in the spotlight of scientific and public concern, such as the possible relationship between climate change and hurricane intensity or the possibility of prolonged drought in the western United States. It is timely, therefore, to revisit the original research plan, assess the progress made, consider potential new emphases, and issue this new edition of NOAA's research plan for 2007-2011.

The current plan emphasizes even more the societal needs that drive NOAA's research and the central role of research in underpinning NOAA's products and services that seek to satisfy those needs. As our nation's social and economic systems grow increasingly complex and interdependent, our vulnerability to environmental stresses likewise increases. In the 21st century, a resilient society and economy depend on informed decisions about dealing with environmental change and managing our resources. Research is at the heart of making informed decisions, and we remain committed to supporting a vigorous and broad portfolio of research to achieve the goals in NOAA's Strategic Plan related to ecosystems, climate, weather and water, and commerce and transportation.

NOAA research is undertaken in partnership with the wider national and international research community, and NOAA continually seeks advice from that community to ensure its research remains vital and relevant. The environmental challenges and opportunities facing humanity demand collaboration across institutions to realize the full benefits of research at NOAA. We look forward to working with our partners in implementing the research described in this plan and ensuring that research is effectively and efficiently translated into meaningful application.

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Executive Summary

This second edition of NOAA's five-year research plan continues to describe the short-term research activities needed to address the major environmental challenges facing society, which we outlined in 2005 in our 20-Year Research Vision. This edition provides specific research milestones to be achieved during FY 2007-2011, and it links these milestones directly to performance objectives in NOAA's Strategic Plan. To reach the milestones, the plan emphasizes the integration of our observational, analysis, and modeling tools that are at the core of all our research.

NOAA's observational requirements range from acquiring unique measurements within the deep ocean to sustaining a climate monitoring network. Our analysis capabilities generate maps and other user products that span the daily weather to the state of the ocean and the atmosphere over the last half century. Our models forecast events as diverse as severe local weather, harmful algal blooms, and climate change. Given this large breadth of observational, analysis, and modeling needs, NOAA cannot achieve the research milestones listed in this plan by itself. The plan, therefore, highlights the importance of our partnerships with researchers in universities, other government institutions, the private sector, and abroad.

This is a plan for action with specific milestones and objectives that will allow us to provide the nation with the information it must have to make the best decisions possible to meet the social, economic, and environmental needs of a dynamic and productive society.

Research to Meet Societal Needs

NOAA is the single Federal agency with operational responsibility to protect and preserve ocean, coastal, and Great Lakes resources and to provide critical and accurate weather, climate, and ecosystem forecasts that support national safety and commerce. Over the next 5 years, we will accomplish this mission by addressing a variety of research challenges, many of which are captured in the following set of overarching research questions:

1. What factors, human and otherwise, control ecosystem processes and impact our ability to manage marine ecosystems and forecast their future state?

2. What is the current state of biodiversity in the oceans, and what impacts will external forces have on this diversity and how we use our oceans and coasts?

3. What are the causes and consequences of climate change?

4. What improvements to observing systems, analysis approaches, and models will allow us to better analyze and predict the atmosphere, ocean, and hydrological land processes?

5. How are uncertainties in our analyses and predictions best estimated and communicated?

6. How can the accuracy and warning times for severe weather and other high-impact environmental events be increased significantly?

Such questions strike at the heart of the most pressing environmental challenges facing our nation today and in the decades to come. Answers to them will provide the public and policy makers with

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the understanding needed to make informed decisions, but these answers will not come easily. The complexity underlying the above questions demands the concerted efforts of NOAA scientists and our research partners to make meaningful progress over the next five years.

Research and NOAA's Mission Goals

The NOAA Strategic Plan organizes the agency's scientific activities around a series of four mission-directed *goals* and one mission support goal. NOAA's research enterprise develops the understanding required for each goal to achieve its mission and associated outcomes under the Strategic Plan.

Ecosystems Mission Goal: Protect, Restore, and Manage the Use of Coastal and Ocean Resources through Ecosystem Approaches to Management

The desired outcomes of this goal are to sustain healthy and productive coastal and marine ecosystems that benefit society and to provide for a well informed public that acts as a steward for coastal and marine ecosystems.

NOAA's Ecosystem Approach to Management (EAM) emphasizes understanding the entire ecosystem in a region, rather than considering single issues in isolation. This approach permits managers to balance societal, economic, and environmental needs with resource usage while preserving ecosystem balance.

Research areas in support of NOAA's ecosystem goal are:

- Advancing understanding of ecosystems to improve resource management
- Exploring our oceans
- Forecasting ecosystems events
- Developing integrated ecosystem assessments and scenarios, and building capacity to support regional management

A recent result of this research is the development of an observing system for the California Current regional ecosystem along the west coast of the United States. This project required extensive collaboration across NOAA, as well as with federal and state agencies, academic institutions, and three regional associations.

Climate Mission Goal: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

The outcomes of the climate goal include a predictive understanding of the global climate system on time scales of weeks to decades with quantified uncertainties sufficient for making informed and well-reasoned decisions.

The research areas in support of the climate goal are:

- Develop an integrated global observation and data management system for routine delivery of information, including attribution of the state of the climate
- Document and understand changes in climate forcings and feedbacks, thereby reducing uncertainty in climate projections
- Improve skill of climate predictions and projections and increase range of applicability for management and policy decisions
- Understand impacts of climate variability and change on marine ecosystems to improve management of marine ecosystems

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- Enhance NOAA's operational decision support tools to provide climate services for national socio-economic benefits.

Recognizing the needs voiced by the Western Governor's Association, the climate goal has undertaken an effort to integrate new and existing climate observations, data, and models into a Drought Early Warning System for the 21st Century. This system is an excellent example of how new design approaches can be used to integrate climate information, allowing policy makers to make better regional decisions.

Weather and Water Mission Goal: Serve Society's Needs for Weather and Water Information

Some key outcomes of this goal are to reduce loss of life, injury and damage to the economy, while providing better, quicker and more valuable forecast information and increasing customer satisfaction with our information and services.

The research areas under the weather and water goal are:

- Improve weather forecast and warning accuracy and amount of lead time
- Improve water resources forecasting capabilities
- Provide information to air-quality decision makers and improve NOAA's national air quality forecast capability
- Improve NOAA's understanding and forecast capability in coasts, estuaries, and oceans

Each year thousands of lives and billions of dollars are lost due to severe storms, floods, heat waves, and other natural events. As the U.S. population grows and continues to shift toward the coasts, the effects of these storms could be amplified greatly. Past and present weather and water research projects aimed at hurricanes, tornadoes, and other high-impact events, seek to increase warning times and improve storm track and intensity predictions to save lives and limit property damage.

Commerce and Transportation Mission Goal: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

The outcome for NOAA's commerce and transportation goal is to enhance national economic performance through the development and use of an efficient, safe, secure, and environmentally sound U.S. transportation system.

The research areas in support of commerce and transportation are:

- Explore, develop and transition emerging technologies and techniques to enhance marine navigational safety and efficiency
- Provide accurate, timely and integrated weather information to meet air and surface transportation needs
- Improve accuracy of positioning capabilities to realize national economic, safety, and environmental benefits
- Develop the information and tools to make reliable decisions in preparedness, response, damage assessment, and restoration

Under this goal, NOAA research will continue to improve the quality and timely distribution of data, forecasting capabilities, nautical charting, and emergency response tools such as air dispersion modeling. This work will require continued and increased emphasis on weather and marine

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observations, improved modeling techniques, accurate positioning capabilities, and enhanced preparedness and restoration abilities.

Technology and the Mission Support Goal: Provide Critical Support for NOAA's Mission

The desired outcome for the mission support goal is to develop ship, aircraft and satellite systems that ensure continuous observation of critical environmental conditions.

There are four key areas that guide our research activity under this goal:

- Advancing space-based data collection capabilities and associated platforms and systems
- Advancing *in situ* and surface-based data collection capabilities and associated platforms and systems
- Overall observing systems architecture design
- Data management, associated visualization technology & models, and related high performance computing and communication

NOAA's observational systems, from satellites above our atmosphere to submersible ocean vessels, underpin all four mission goals outlined in this plan, and they are critical to our continued leadership and support of international environmental assessments, such as the Intergovernmental Panel on Climate Change (IPCC). NOAA research for this mission support goal aims to ensure we meet expanding demand for new types of Earth measurements along with greater data accuracy, geographic coverage, and accessibility.

Continued Excellence in Research

NOAA is committed to ensuring our research is of demonstrable excellence and is relevant to societal needs, providing the basis for innovative and effective operational services and management actions. NOAA has improved and streamlined its process for transferring research into applications by adopting a NOAA Transition to Application policy and implementation procedures which have put a formal transition process in place for identifying mature research and accelerating the rate at which this research transitions into applications.

NOAA uses a hierarchy of mechanisms to ensure the relevance and excellence of its research. All proposed research is analyzed for its significance to addressing known requirements, compared against competing alternatives, examined for its performance characteristics, and its cost compared to the expected outcome. A significant portion of research funds are awarded both externally and internally through competitive proposal processes. NOAA exercises a system of external reviews to ensure all levels of our research organization are evaluated regularly. Finally, we employ an agency-wide Research Council and an external Science Advisory Board, to ensure that our research products are of the highest quality, relevance, and value to the American public.

Moving Forward Through Research

At its core, NOAA research aims to anticipate societal and environmental concerns of the 21st century, providing the timely and accessible delivery of data, knowledge, technology, and products to decrease vulnerability and enhance opportunity for the American people in a changing and competitive world. In the next five years, NOAA research will continue addressing challenges already identified and new ones certain to emerge.

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1. Introduction

NOAA's Mission

To understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs

Over the next several decades, population growth and changing demographics, energy security, climate change, advances in technology, and the use of natural resources will drive society's demands. Populations are increasing and shifting toward urban centers and coasts. The growing need for energy security will lead to increasing consideration of alternative energy sources and imaginative application of fossil fuels. Global climate is changing with regional consequences and is gaining increasing attention from broad elements of society. Widespread advances in technology offer new opportunities for improving the quality and effectiveness of research but also will challenge society as it adjusts to increasingly rapid change. The risk of depleting the natural resources that sustain our economy increases with the ever-growing demand for multiple uses amid continued environmental change.

NOAA is the single Federal agency with operational responsibility to protect and preserve ocean, coastal, and Great Lakes resources and to provide critical and accurate weather, climate, and ecosystem forecasts that support national safety and commerce. Research at NOAA has improved our ability to offer timely and accurate storm forecasts, including major hurricanes, tornadoes, snowstorms, and tsunamis. Working together with our partners, we provide a unique foundation of information documenting the natural and human-related drivers of climate change and have improved and extended our ability to map the ocean floors and coastal waters where commerce is so vital. We are delivering the information necessary for developing sustainable fisheries yields while promoting healthy marine and coastal ecosystems. NOAA is the agency that integrates research in all of these areas to provide the best possible information for the benefit of society. Operations at NOAA have met societal needs owing in good part to this research, which involves acquiring new information as well as testing new technologies and approaches. By tapping and focusing the creativity of its scientists and those in its partner institutions, NOAA has progressed in pace with today's rapidly changing world, expanding and improving vital services, and providing ultimately for a better, healthier, and safer society.

Overarching Research Questions

1. What factors, human and otherwise, control ecosystem processes and impact our ability to manage marine ecosystems and forecast their future state?
2. What is the current state of biodiversity in the oceans, and what impacts will external forces have on this diversity and how we use our oceans and coasts?
3. What are the causes and consequences of climate change?
4. What improvements to observing systems, analysis approaches, and models will allow us to better analyze and predict the atmosphere, ocean, and hydrological land processes?
5. How are uncertainties in our analyses and predictions best estimated and communicated?
6. How can the accuracy and warning times for severe weather and other high-impact environmental events be increased significantly?

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Nevertheless, NOAA is not resting on past accomplishments. As social and economic systems evolve and become more complex, the tools and information needed to promote growth, to preserve and improve human and environmental health, to develop and maintain a viable national infrastructure, and to provide security for present and future generations must advance as well. It is through research that society gains the understanding to make informed decisions in an increasingly complex world

NOAA will continue to pursue its long-term vision of what must be done for the nation through systematic and sustained research planning. This plan is designed to lead NOAA's research during the next five years by establishing the framework and strategies required to meet society's evolving needs. It is linked to the societal benefit areas identified in the NOAA 20-Year Research Vision, and it is designed to inform NOAA's partners, Congress, constituents, and the public of the progress its research is making, and of its societal benefits.

The breadth and depth of NOAA's research for the next five years is exemplified by the six overarching research questions in the box. They are illustrative of the research that drives the agency. These complex questions require a diversified research agenda, directed by mission needs but involving an array of public and private research partners working closely with NOAA scientists. NOAA research programs and their collection of projects seek to answer these and similar questions. For example, NOAA research led to the development of a radar technology that has extended tornado warning lead times from a few minutes to 12-13 minutes. Can we detect a tsunami before it strikes, or do we continue to rely on unreliable inferences of tsunamis directly from an earthquake event that might generate them? The development of new deep ocean buoy technologies to detect tsunamis while they are still far out to sea and sophisticated computer models to predict their magnitude and when they will hit the coast have answered that question by improving tsunami warnings and reducing false alarms. Research into the relationship between climate and the Bering Sea ecosystem has led to improved management of fisheries. NOAA research and ecosystem assessments have documented evidence that warming in the Arctic system has favored the pollock fishery in Alaskan waters. NOAA conducts research to provide such information and tools to enable decision makers to manage resources efficiently and effectively. A well planned and focused research effort that enlists workforce creativity not only will enable NOAA's near-term goals to be achieved, but also will position the agency and society to make informed decisions in the decades to follow.

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2. Linking with our 20-Year Research Vision

This plan outlines the research that NOAA will pursue over the next five years as it works toward attainment of the 20-Year Research Vision (http://nrc.noaa.gov/Docs/Final_20-Year_Research_Vision.pdf). The Vision provides the foundation for NOAA's longer-term research and acknowledges the need for NOAA to address the interactive nature of the components of the global ecosystem. Humans are a part of any ecosystem; their actions affect these systems and in turn these systems influence the activities of humans.

The NOAA 20-Year Research Vision identifies major societal needs that this five-year plan will address through improved and well integrated research. The drivers of anticipated change – population growth, energy security, resource use, climate change – lead to pressures on food production, water availability, and ecosystem health, involve increasing risk related to acute and chronic pollution, and have implications for economic and human health. The Vision notes the role of complex feedbacks that can only be understood through an integrated approach involving observations, analysis, and modeling, which is emphasized in this five-year research plan. This approach will require improved knowledge about entire ecosystems. It will require increased attention to societal demands, and it will require increased emphasis on ecological, oceanic, and atmospheric monitoring. Models addressing atmospheric processes rely on oceanic, atmospheric, and terrestrial observations to generate forecasts. Ultimately, ecological forecasts will include details of the changing environment that influence the productivity and behavior of our living resources. The vision of providing improved forecasts will result from a better understanding of processes that can only come from integrating observations and analysis. Improved forecasts in turn can lead not only to reliable warnings such as the need for beach closures, but also to better management and optimized use of our ocean and coastal resources, which are in constant demand for multiple uses.

This plan aligns NOAA's research along a path toward a broader understanding of the global ecosystem as a whole to address the dynamic array of social, economic, and environmental needs we face today and will face in the future. Research design and implementation will rely increasingly on observational requirements identified through analytical modeling efforts. Scientists will make increased use of expanding computer power to consider entire ecosystems, including humans, as we improve storm warnings and air-quality forecasts, develop ecological forecasts, provide seasonal and decadal climate predictions with smaller uncertainties, and extend forecasts of weather and ocean conditions further into the future.

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3. Framing NOAA’s Future Research

3.1 Societal Context

> ***US/IEOS Societal Benefit Areas***
>
> - Improve Weather Forecasting
> - Reduce Loss of Life and Property from Disasters
> - Protect and Monitor Our Ocean Resource
> - Understand, Assess, Predict, Mitigate and Adapt to Climate Variability and Change
> - Support Sustainable Agriculture and Forestry and Combat Land Degradation
> - Understand the Effect of Environmental Factors on Human Health and Well-Being
> - Develop the Capacity to Make Ecological Forecasts
> - Protect and Monitor Water Resources
> - Monitor and Manage Energy Resources

Over the next five years, research at NOAA will address those societal and environmental trends that are of increasing importance to decision makers. National and global population growth and redistribution towards coastal regions, climate variability and change, human and natural alterations of ecosystems, agricultural needs in the face of changing water supply and water quality, and other pressing questions are creating an increasing demand for information and services to help people make the best possible decisions. These issues will be of particular importance as coastal populations increase. National and international planning documents, like the NOAA 20-year Research Vision, the Strategic Plan for the U.S. Integrated Earth Observation System (US/IEOS), the Global Earth Observations System of Systems (GEOSS) 10-Year Implementation Plan, the National Research Council’s (NRC) “Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,” and the Ocean Research Priorities Plan, have identified a variety of societal needs for environmental information (see Box for one example of societal benefit areas). Satisfying these needs will require NOAA to manage more intensive data streams, develop improved approaches to using them, and build the modeling capabilities to integrate data from different parts of the Earth system.

NOAA’s research in the natural and social sciences supports all that NOAA does. It seeks to ensure our nation remains *resilient* in the face of challenges, *competitive* in taking advantage of opportunities, and *intelligent* in assessing those challenges and opportunities to make plans accordingly.

Resilience

> ***In terms of financial loss, seven of the ten most expensive hurricanes in US history occurred in the 14 months from August 2004 to October 2005, including Katrina ($40.0 billion insured losses), Rita ($4.7 billion), and Wilma ($6.1 billion).*** *-- Insurance Information Institute, NY, NY, December 7, 2005*

One of NOAA’s most fundamental commitments is to protect the nation against loss of life and property and threats to human health from natural forces. The agency fulfills this obligation on a routine basis, most visibly perhaps in connection with 2005’s Hurricane Katrina, whose strike on the coastal zone of Mississippi, Louisiana, Alabama, and Florida severely impacted lives and the region’s economic well being. The Atlantic hurricane season of 2005 illustrates how important it is to improve the resilience of our communities and businesses to natural hazards, particularly those affecting our coasts. With only a quarter of the nation's total land area, coastal watershed counties nevertheless account for half of the nation's population and economic output.

The coasts are not the only section of our nation vulnerable to natural disaster. The Midwest, for instance, is notorious for tornadoes that rip through communities. NOAA’s improved forecasts and warnings over the last decade are reducing the losses that tornadoes bring with them. Moreover, the hazards we must guard against are not always natural; often they are caused or facilitated by humans. Invasive, non-indigenous species and their associated costs are estimated to have exceeded $120 billion in damage or control measures in the United States in 2005. According to the Centers for Disease Control and Prevention, the nation’s largest drinking water disaster, caused by a *Cryptosporidium* bloom from storm-driven wastewater overflow in Lake Michigan in 1993, contributed to the deaths of over 100 people, sickened over 400,000, and cost $96 million. Based on NOAA research, the drinking water intake for Milwaukee has since been moved to prevent future problems.

> ***Between 1992 and 2004, NOAA’s NEXRAD radar system prevented over 330 fatalities and 7,800 injuries from tornadoes, at a monetized benefit of over $3 billion, compared to a total capital investment of less than $1.7 billion. --*** *The Value of Tornado Warnings and Improvements in Warnings, AMS 2006*

Whether hazards are coastal or inland, caused by nature or man, or the losses felt immediately or gradually, NOAA works to improve the nation’s resilience in the face of such destruction. Adverse consequences of environmental hazards are expected to grow larger year by year simply because of demographic trends. Local decision makers must have the right information when and where they need it, and they must be connected to a network of knowledgeable experts to help them assess their choices.

Competitiveness

While we must be capable of facing challenges that confront us, we must also take advantage of opportunities presented to us. Inasmuch as the economy depends upon the natural world, NOAA’s operational capabilities enable innumerable economic efficiencies every day, and its research improves these efficiencies and explores new methods of realizing them. Such benefits are readily visible in the applications of NOAA’s weather forecasts and warnings. Variation in economic output due to weather across sectors ranges from 1.4 percent in wholesale trade to 21 percent in agriculture. Weather is the number one disruptor of many businesses.

The nation’s commerce depends upon transportation through a wide array of environmental conditions. The marine transportation system, in particular, depends on high-accuracy, three-dimensional charting of the oceans, coasts, and Great Lakes, real-time positioning data, and accurate coastal forecasting of waves and currents. These are essential public goods provided by NOAA, which will become increasingly important in the years to come. According to the Department of Transportation, “U.S. international container traffic is projected to at least double from 2001 to 2020. Nowhere will this pressure be felt more than at U.S. ports.” Geodetic research at NOAA constantly improves this vital component of the nation’s information infrastructure.

> ***Beyond the value derived from species and habitats, the portion of the U.S. economy that depends directly on the ocean as a whole is very large, with 2.2 million people employed and $197 billion in output in 2003.*** *– National Ocean Economics Program*

With respect to air transportation, the Federal Aviation Administration (FAA) estimates that up to $4 billion is lost annually as a result of weather related air traffic delays that would be preventable with better, more timely information. NOAA, in partnership with the FAA, is conducting research to mitigate the impacts of weather on the air transportation system. Enhancements to weather observations and forecasts are an essential part of this research, but the capability to have rapidly updated, high resolution weather information integrated into the air traffic management decision making process is the key to reducing the economic impacts of adverse weather conditions. Episodes of heightened space weather are also significant, as they can disrupt communications and increase passengers' radiation exposure. NOAA has developed the operational capability to predict such events, thus allowing agencies and businesses to respond as needed.

Our economy derives incredible value from services provided by ecosystems. Commercial and recreational fishing industries annually contribute over $60 billion to the gross domestic product. NOAA research into rebuilding fish stocks and aquaculture is critical to ensure long-term sustainability of commercial fisheries. Recreational use of the coasts is particularly significant. The economies of the 51 beaches of Los Angeles and Orange counties alone are valued at almost $5 billion per year, and we currently are conducting research leading to the development of forecasts of beach contamination to help reduce the risks to human health. NOAA research on marine organisms has resulted in the discovery and description of over 1,000 compounds that could be developed into new drugs and thus may be vitally important to the health industry in the future.

NOAA research is making important contributions to the energy sector of our economy. U.S. electricity generators already save $166 million annually using 24-hour temperature forecasts to improve the mix of generating units that are available to meet electricity demand. The economic viability of alternative energy sources, like hydroelectric, wind, solar power, or bio-fuels, will depend upon increasingly accurate, location-specific weather and climate information. Advanced modeling techniques for wind energy, for example, have already allowed traders to increase earnings on the Short-Term Power Exchange by as much as 7.5 percent. Looking beyond the next 5 years, there is the potential for NOAA research to support the development of hydro-kinetic energy production from ocean currents, as well as methane hydrates which contain substantial energy reserves trapped in marine sediments.

Finally, to sustain a national capability in these and other areas of research, NOAA is committed to the development of the next generation of scientists. NOAA will support and train young scientists through its cooperative institutes and other centers of research, as well as through various post-doctorate, scholarship, and intern programs. Many NOAA scientists serve on university committees and work with students in fields related to NOAA research, thus helping ensure the interest and capability of a younger generation whose skills will be necessary to ensure a competitive America.

Informed Decisions

NOAA provides the nation with scientifically rigorous, unbiased assessments of the environmental challenges and opportunities facing us to enable choices that are often difficult and controversial. NOAA assumes an important role, for example, in studying the effects of new and existing energy technologies, from the climatic effects of greenhouse gases to the habitat consequences of offshore oil drilling and wind power. Such studies are critical to making informed decisions about the tradeoffs, risks, and consequences between the benefits of increased energy supply and the possible costs of environmental damage.

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The oceans illustrate a prime example where our research intersects with the nation's need to make intelligent choices about managing resources. In its 2004 report, the U.S. Commission on Ocean Policy found the nation's oceans, coasts, and Great Lakes were in a desperate state and recommended the administration "improve the federal agency structure by strengthening NOAA" as well as "double the nation's investment in ocean research, launch a new era of ocean exploration, and create the advanced technologies and modern infrastructure needed to support them." NOAA has been called upon to implement the reforms outlined in the Ocean Action Plan and the Ocean Research Priorities Plan to improve decision making at the national, regional, state, and local levels, to coordinate and integrate ocean, coastal, and Great Lakes programs, and to implement an ecosystem approach to management.

The nation realizes that "environmental" issues are social issues by their very nature, as human relations, e.g., the economy, safety, security, and culture, are embedded within the processes and structures that comprise ecosystems. NOAA's role is to study environmental phenomena at the intersection of multiple disciplines and convey the knowledge gained to decision makers across the nation and beyond. This includes research in the social sciences to account for how the environment affects society and vice versa and how well NOAA is accomplishing its mission to meet society's needs. Interdisciplinary research to place environmental issues within their social context is critical to enable the agency, its customers, and the nation as a whole to make informed decisions when faced with difficult tradeoffs that inevitably must be made. Only through research can we reduce uncertainty about the relationships between humans and nature.

3.2 NOAA Now – A Special Agency with a Unique Mandate and Capabilities

With the responsibility to manage ocean, coastal, and Great Lakes resources and provide weather and climate forecasts and warnings, NOAA occupies a unique position in the federal government's monitoring of the atmosphere, ocean, and coasts. Accomplishing NOAA's mission requires it to develop a comprehensive understanding of the forces responsible for shaping Earth's present environmental state and its future evolution. This challenge is made all the more daunting by the complexity of the natural system we live in. The planetary radiation budget sets the stage for thermodynamic processes in the ocean and atmosphere that modulate how and where heat is stored, transported across the planet, and exchanged among the atmosphere, land, and ocean. The vagaries of this planetary heat engine determine our weather and climate and permit ecosystems to flourish or become stressed. Compounding the challenge to understand the physical and chemical components of the Earth system are the complexities of biological systems and how they interact with the ever changing physical world.

Variability within this planetary system occurs at all spatial scales and on multiple time scales from minutes to decades and longer. For example, local weather forecasts and warnings rely on observations from both near and far and on numerical models running on global, regional, and local scales. The goal of NOAA's research is to improve measurement of the key environmental variables needed to characterize Earth's environment, to advance understanding of the physical, chemical, and biological processes in the atmosphere, ocean, and land surface, and to enable predictions of future changes important to society. The expertise needed to do this research encompasses many disciplines; therefore, the research approach must be interdisciplinary and must integrate the study of the natural environment with human activities and societal needs. To meet its responsibilities, NOAA has developed considerable expertise in the relevant scientific disciplines and worked to establish partnerships with researchers outside the agency to complement its capabilities. Together, the NOAA-based research community represents a tremendous asset to the nation in helping it deal with environmental issues.

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Research at or supported by NOAA has led to improvements in the information products and services it provides the nation. In the last two years alone, since the publication of its original research plan, NOAA research has dramatically improved the ability to offer timely and accurate storm forecasts. It has provided a strong foundation of information about the natural and human-related drivers of climate change. It has improved and extended the ability to map the ocean floors and coastal waters where commerce is so critical. It has provided the information necessary for developing sustainable fisheries yields while promoting healthy ecosystems. Through the efforts of NOAA's scientists, support operations, and partners, NOAA remains well positioned to provide vital services and information for society's future decisions.

3.3 NOAA Next – Improved Products, Services, and Information through Integrated Research

While NOAA research has accomplished much, it is becoming increasingly clear that the environmental challenges ahead require new research paradigms, foremost among these being a problem-focused perspective in which research transcends traditional organizational and disciplinary boundaries. Recognizing that the natural systems it studies interact and produce outcomes that can best be understood by approaching them holistically, NOAA plans to develop a comprehensive Earth system analysis and modeling capability. This capability will encompass weather, climate, and ecosystems, including the social and economic processes that are embedded within these systems.

To assume a problem-focused perspective, NOAA research must include what products and services our customers need, the form in which they need them, and how we might better provide them. Making wise investment decisions agency-wide involves research and analysis of how valuable NOAA products are and why they are valuable. Without adequate understanding of the user community, the best science in the world could lack real-world utility. Only with this knowledge in hand can NOAA understand how its operations can be improved, where natural science research needs to be expanded, and what financial, workforce, and infrastructure resources will be required. The NOAA of the future will base its decisions on sound social science research to provide the best value for the public.

Global observing systems, computer modeling capabilities and human intellect will continue to be applied to answer critical, fundamental science questions that lead to enhanced understanding of complex systems and to new tools and technologies that help humans adapt to and manage these complex systems. NOAA's research priorities are determined to a large extent by their societal relevance, which in turn will be judged through increased outreach to users and decision makers, facilitated by increased support for, and use of, social science research. Because the problems to be tackled will be increasingly interdisciplinary, we will turn even more aggressively to programmatic approaches that encourage cross-cutting research and to scientific approaches that enable a comprehensive Earth system analysis and modeling capability.

To provide the future products, services, and information needed by society, robust environmental observation, assessment, and prediction capabilities will be needed. Over the next five years and beyond, NOAA and its regional, state, national, and international partners will exploit new technologies to better understand, monitor, and predict the behavior of Earth's complex ecological systems at global, regional, and local scales .NOAA will achieve this capability by working with its federal and state agency partners to establish regional observing systems and with the international community to build an integrated Global Earth Observation System of Systems, ultimately linking it with comprehensive Earth system models. These models will be used to analyze and predict the

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state of the atmosphere, oceans, and land surface, taking into account the hydrological and biogeochemical cycles that couple these components of the Earth system. The integrated observing and modeling system will, in large part, be defined by and be responsive to local needs; at the same time it will provide an international framework that will allow us to predict the local impact of global phenomena and the global consequences of local activities. In this context, research and assessments in social science and in the economics of weather, climate, and ecosystems will become increasingly important in expanding our understanding of processes and structures that describe how humans interact with the environment. This research includes understanding the most effective means of communicating our science and information to users and assessing the economic value of this information.

3.4 Transformational Research in NOAA

As a science-based agency, NOAA depends on long-term, systematic research and development to meet its mission goals through incremental improvements in its products, services, and science applications. A research enterprise of this design lends itself well to NOAA's research enterprise structure and to the planned and executed achievement of its research milestones. On the other hand, technological innovation and leaps in scientific knowledge (i.e., transformational research) have contributed revolutionary improvements to NOAA's mission. Doppler radar, for example, dramatically increased lead times for tornado and severe weather warnings to the public; discovery and understanding of the processes affecting the stratospheric ozone layer led to international agreements and management toward the recovery of the global ozone layer; discovery and understanding of the El Niño phenomenon and the development of the Tropical Atmosphere Ocean (TAO) buoy array led to dramatic improvements in seasonal to interannual climate predictions. These are groundbreaking discoveries that fundamentally changed practices and national policy. NOAA will continue to respond to client demands for more reliable, credible, and useful products by taking transformational approaches to how it develops and communicates information, such as the increased use of probabilistic forecasts and utilizing an ecosystem approach to management. NOAA's treatment of Earth as a single system will lead to better integration of our weather, ocean, and climate research with an ecosystems approach to conducting research.

Such high-payoff activities require a Federal presence to attain long-term national goals but also contain an element of risk. Often, the uncertainty in the outcome is high, yet potential payoff is also high. NOAA laboratories, along with private sector and university partners, play a key role in NOAA's research enterprise by enabling high-risk research and development. NOAA will continue to find mechanisms and partners for transformational research – research that will spur technological innovation and leaps in scientific knowledge to fuel the nation's economy and improve our quality of life. NOAA will foster a research organization with an appropriate rate of radical innovation that can transform our scientific environment, emphasizing areas of greatest scientific and technological opportunities and potential benefits to the nation.

3.5 The Role of NOAA's Research Partners

Extramural research partners complement NOAA's intramural research by providing expanded scientific and technical expertise and sources of new knowledge and technologies. NOAA's research partners help maintain its international leadership in environmental research. Research partners include academic institutions, other federal agencies, the private sector, non-profit organizations, state, local, and tribal governments, and the international community. NOAA's government partners provide means for leveraging limited resources. Several programs seek to identify native or local experiential knowledge that can provide valuable insights traditional scientific methods may not capture. Some examples of these programs are Sea Grant Extension,

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the Regional Integrated Sciences and Assessments (RISA) program, and NMFS Cooperative Research programs. With these research partners, NOAA maintains the highest standards of ethical and scientific integrity and scientific openness.

Because universities are in the vanguard of developing new structures to integrate across traditional disciplinary lines, they support NOAA's needs for innovation in Earth system science and ecosystem assessment and forecasting. In addition to providing NOAA with cutting edge and transformational research, academia is, of course, the source of the next generation of scientists.

The private sector will help ensure NOAA research remains relevant to user needs and at the cutting edge of technology (e.g., high performance computing, unmanned aircraft systems, and satellite sensors). There are also long-term development collaborations with the private sector. NOAA participates in many forums that enable user groups, the private sector, governmental organizations, and product providers to share research results and foster the development of practical applications.

NOAA employs a variety of mechanisms to fund extramural research within appropriated funding levels and Congressional direction. These mechanisms include competitive, merit-based peer-reviewed grants and cooperative agreements. These grants and cooperative agreements are awarded to outstanding scientific institutions according to procedures detailed in the Department of Commerce Grants and Cooperative Agreements Interim Manual at *http://oamweb.osec.doc.gov/GMD_interimManual.html*. NOAA announces award competitions prior to the start of each fiscal year with a notice of the availability of grant funds for the upcoming fiscal year via a *Federal Register* notice. This notice provides a single source for program and application information related to NOAA's competitive grant offerings. Additional program initiatives unanticipated at the time of the publication of the notice may be announced through both subsequent Federal Register notices and at *http://www.ago.noaa.gov/grants/.* Specific funding decisions by agency managers will be based on research priorities identified in NOAA's 5-Year Research Plan and specific opportunities identified by NOAA in the execution year.

3.5.1 Role of Universities

The complexity associated with conducting Earth System and ecosystem-level research requires NOAA to work with teams of scientists at research institutions, in addition to research conducted by independent scientists who possess core capabilities that benefit NOAA research. NOAA-funded research centers play a vital role in enhancing our capabilities and in broadening NOAA's ability to provide the expanding array of environmental assessment and predictions required to address societal needs. The number of researchers involved with NOAA-funded research at these individual centers can exceed several hundred. Some of the largest centers are part of NOAA's Cooperative Institutes (CIs), the National Sea Grant College Program, and the Educational Partnership Program (EPP) with Minority Serving Institutions.. Please see the Appendix for descriptions of NOAA's laboratories, centers, Sea Grant, EPP, and Cooperative Institutes. Education and training are important components of every Cooperative Institute and Sea Grant program. In 2006, nearly 1200 faculty, scientists, and students were supported at NOAA Cooperative Institutes. Laboratories, Sea Grant, and science centers support graduate and undergraduate fellowships, which increase the number of scientists and breadth of scientific and technical expertise available to NOAA, as potential employees or grantees. For example, NOAA's Sea Grant Program conducts three fellowship programs that are intended to provide research and policy graduate students with exposure to working in the federal government: the Dean John A. Knauss Marine Policy Fellowship (Knauss Fellowship) program, the Sea Grant Industry Fellowship program, and the joint Sea Grant/National Marine Fisheries Service fellowship program for the

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study of population dynamics and marine resource economics. In many cases, these fellowships lead to positions within the federal government work force and present a unique opportunity for NOAA and other federal scientific agencies to develop a strong, highly educated workforce.

Cooperative Institutes are NOAA-supported, non-federal organizations that have established an outstanding research program in one or more areas directly related to NOAA's long-term mission needs. Established at research institutions, they also have a strong education program with established graduate degree programs in NOAA-related sciences. A CI engages in research that requires substantial involvement of one or more research units within the research institution and one or more NOAA laboratories or programs. The CI provides significant coordination of resources among all non-government partners and promotes students and postdoctoral scientist involvement in NOAA-funded research. The CI provides mutual benefits with value provided by all parties. NOAA creates, uses, and manages CIs according to NOAA's policy on CIs, adopted in September 2005 (http://www.corporateservices.noaa.gov/~ames/NAOs/Chap_216/naos_216_107.html).

NOAA's National Sea Grant College Program serves as a unifying mechanism within NOAA to engage top universities in meeting NOAA's research mission. As a result of its stable infrastructure and location in every coastal and Great Lakes state, Sea Grant is capable of bringing university expertise and resources to bear on research and outreach challenges of federal and national importance. Sea Grant's research priority areas match very closely the societal themes identified in the Ocean Research Priorities Plan. In addition, the interagency Regional Research and Information Plans are administered by Sea Grant, utilizing its national infrastructure and the strength of Sea Grant's facilitation capabilities to bring together federal, state, and local governments, as well as non-governmental organizations, to develop research priorities based on regional needs.

3.5.2 Federal and State Agencies

NOAA scientists and staff facilitate the coordination and planning of research and development programs by actively participating in federal coordinating committees and task forces, including the National Science and Technology Council's Committee on Environment and Natural Resources (CENR) and Joint Subcommittee on Ocean Science and Technology (JSOST), the Climate Change Science Program (CCSP), the Climate Change Technology Program (CCTP), and the National Oceanographic Partnership Program (NOPP). Coordination in these organizations and other bilateral and multiagency activities leads to shared goals and objectives, leveraged budgets, and collaborative research.

NOAA also works closely with its state partners in conducting research to support environmental stewardship and mitigation of extreme environmental events. NOAA collaborates with regional associations supporting the Integrated Ocean Observing System to conduct research and collect ecosystem data that will lead to ecological forecasts and integrated assessments on all relevant time scales. State partners play a significant role in the design of products and services - and thus the research required to develop them – to be used for the planning and mitigation of drought, tsunamis, poor air quality, hurricanes, harmful water quality, and other high impact events.

3.5.3 Private Sector

NOAA's scientific efforts foster a close relationship between the agency and the private sector, filling a critical role in the development of new technologies. The agency's emphasis on integrated observation systems has forged a stronger link between the agency and private sector interests

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increasingly dependent on frequently updated and reliable information. For example, NOAA's global greenhouse gas observing system operates through collaboration with international partners who are often in the private sector. Another example of research between NOAA and the private sector includes the establishment of cooperative fisheries research programs through Sea Grant, which encourage fishermen to use their boats as research platforms and actively participate in research initiatives.

In addition, NOAA programs provide competitively awarded funding for private sector interests to conduct research. For example, NOAA recently awarded contracts totaling $2 million to provide critical information for the development, implementation, and delivery of the Integrated Ocean Observing System (IOOS). This information will guide the integration of the disparate pieces of the U.S. ocean and coastal observing system into an interoperable environmental information network that will help launch new capabilities for ocean observing and will contribute to the Global Earth Observation System of Systems.

The NOAA Small Business Innovation Research (SBIR) program contracts with small businesses to find solutions to research problems identified by agency scientists. The major benefit of the program is the ability to entrain outstanding private talent to address current research needs and the development of technological innovations that lead to significant research benefits to NOAA. Information on the program, including solicitations, can be found at http://www.oar.noaa.gov/ORTA/SBIR.

Under P.L. 99-502, NOAA laboratories can enter into Cooperative Research and Development Agreements (CRADA) that address critical agency research needs with a private sector partner providing technical support. The private sector partner is allowed to commercialize products derived from the CRADA. The NOAA portion of the Department of Commerce Technology Transfer report identifies recent NOAA CRADA activities and is located at http://www.technology.gov/reports.htm.

3.5.4 International Research Partners

NOAA's mission is inherently international in nature. Consequently, NOAA recognizes the value of international partners, learns from their experiences, and benefits by working together on common issues. NOAA embraces the international scale of scientific collaboration, ranging from atmospheric and climate science to ecosystem research and natural resource management. NOAA's research efforts involve partners from hundreds of countries, institutions, and international and regional organizations. This work is conducted under formal agreements as well as through informal collegial relationships.

Through its endeavors, NOAA is recognized as a global leader and a valued partner. International engagement is an integral part of, and essential to, achieving NOAA's mission. Understanding, predicting, and responding to changing trends and vulnerabilities in Earth's environment is a global challenge that demands collaboration with the international scientific community. This is accomplished by engaging in multilateral organizations and in international projects, by promoting the adoption of NOAA policy priorities and practices (such as free and open exchange of data, adaptive management practices, or the architectural design of Earth observing systems) by other countries and international organizations, by exchanging data, information, and expertise with colleagues and partners in both formal and informal settings, and by providing training, technology transfer, and technical assistance internationally to build the capacity of our partners and thereby raise the level of global capabilities.

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3.6 Communication of Research

NOAA scientists are expected to publish their work in the peer-reviewed literature, and, indeed, many NOAA findings appear in leading national and international journals., NOAA research publications are highly cited, for example in international state-of-science assessments on climate, the ozone layer, and air quality, which provide key scientific information that is relied upon by decision makers on these topics. Regional Fishery Management Councils routinely rely upon assessment reports from NOAA scientists to make recommendations on regulatory matters. Scientific findings and breakthroughs are also announced via press releases and media conferences. Onboard technology brings underwater researchers into the classroom. NOAA exhibits at scientific, trade, and other conferences illustrate the impact of its research on the daily life of the nation. Posters, videos, and podcasts are also used by NOAA to reach out to the public. NOAA has recently expanded partnerships with aquariums and science museums, as well as media and groups like the National Science Teachers Association. There are also targeted efforts to communicate science through NOAA's Ocean Exploration and Sanctuaries and Reserves programs. Internally, NOAA communicates to its employees and partners through websites and other material

NOAA's research contributes substantially to the body of Earth science knowledge. Communicating the results of NOAA's research supports the agency's mission as well as informs and excites audiences from decision makers to the next generation of scientists and engineers. NOAA research is critical to many decisions that affect the nation, from an individual wanting to know the likelihood of severe weather for the day to policy makers needing to know the state of the science before crafting legislation.

NOAA seeks to provide the best scientific advice possible and, to this end, encourages open, peer reviewed dissemination of its findings. NOAA strongly believes it is the duty of its scientists to seek truth and inform the public of their findings. For more than three decades, NOAA has communicated its pre-eminent science with the public openly and freely. It is a standard that will continue in the years to come.

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4. Research Tools for Improving Products, Services, and Information

The increasingly broad array of societal issues for which NOAA provides decision support requires improving and extending the range of environmental analysis and modeling capabilities, both regionally and globally. Models and data assimilation systems provide the essential forecasting and analysis tools for decision making. Extending the timescale of forecasts to seasons and beyond, requiring the use of coupled ocean-atmosphere-land models, is needed for more effective resource management for water, agriculture, energy, and the economy. Addressing these interrelated societal needs in the coming decades will require a comprehensive, ecosystem-based approach.. The complexity of an ecosystem approach to management demands a suite of linked models, tools, and technology to provide a scientific basis for decision-making in virtually all that NOAA does, including managing fisheries, forecasting weather, predicting air quality, understanding and assessing climate change, and protecting and preserving oceans and coasts. To achieve this full capability, NOAA will need to develop a system of integrated analysis and forecasting over the next decade. This system must rely on a solid base of integrated observations, from which improvements in understanding through analysis can ultimately be translated to better weather, ecosystem, and climate forecasts. The approach must be applicable to regional issues as well as global assessments.

4.1 Integrated Observations

The nation and world need an effective global observing and data management system to support science-based modeling that leads to a better understanding of global Earth systems and regional ecosystems. NOAA operates a broad array of observing systems that support this goal at scales ranging from local to global and is active in contributing to GEOSS and its nine societal benefit areas through its contributions to the US Integrated Earth Observation System (IEOS). NOAA observing systems collect data on over 500 different types of environmental variables, many of which are directly relevant to research into environmental systems processes. These observing systems include satellites in polar and geostationary orbits, moored and drifting buoys, globally distributed atmospheric observatories, ground based radars and weather stations, and observations and surveys from ships, submersibles, and aircraft. NOAA approved an integrated observing systems and data management target architecture in 2006 to ensure information from these myriad systems are combined effectively to support the needs of both the research community and decision makers. The integrated architecture will focus on providing environmental information to end users and sustain NOAA's capability to collect and manage ever increasing amounts of environmental data. Observing System Simulation Experiments (OSSE) will be used to help optimize the design of the global observing system, as well as to evaluate the potential impact of proposed observing systems, and to prepare for and accelerate the transition of new observing systems from research to operations. OSSE capabilities are well developed for large-scale weather prediction and will be developed and expanded for ocean, climate, ecosystem, and regional weather applications.

Investigating and testing new technologies or approaches to make improved measurements of environmental parameters will continue to be an important component of NOAA research. Research into new observing technologies could result in fielding new systems that support research into Earth system processes, using data from a variety of "operational" and "research-oriented" observing systems to understand key Earth system processes (e.g., the effects of climate-forcing parameters such as carbon dioxide, land use impacts, the relationship of evolving air temperature profiles and climate, and ecosystem-climate interactions.)

Through its observing and data management architecture and requirements and investment analysis processes, NOAA remains engaged in an extensive effort to sustain and improve its capability to support both operational forecast products and Earth systems research efforts. In addition to prioritizing and integrating its observing systems, NOAA is also developing an integrated data management capability. Integrated data management is critical because it will enable users to effectively search for, access, and retrieve Earth information and data from different observing systems over various temporal and spatial scales.

4.2 Environmental Systems Analysis

Diagnostic analysis of system components is critical for understanding causes and feedbacks of impacts on natural systems. This is important on regional and global scales. For example, sustaining productive ecosystems and restoring damaged ones depend on the ability to understand and predict the impacts of human activities and natural processes on those systems and to forecast ecological change. Policy makers, natural resource managers, regulators, and the public often call on scientists to estimate the potential ecological changes caused by these natural and human-induced stressors and to determine how those changes will impact people and the environment. During the past decade, using technological and scientific innovations, scientists have developed and tested forecasts in ways that were previously not feasible. Through its comprehensive research, NOAA is developing the knowledge about ecosystem structure and function (i.e. physical, chemical, biological and human interactions) necessary to develop ecosystem forecasts. New research tools and processes will address the human component of the ecosystem. Diagnostic modeling and coupled biological-physical-chemical models are key tools for providing the link between observations and predictions and improving our understanding of how the components of the Earth system function as a whole. In doing so, NOAA is able to provide the steps necessary to improve predictive models that accurately reflect the diverse forcing agents present.

In addition to regional foci, many recent diagnostic efforts have dealt with the global Earth system. For example, in the last decade there have been several reanalyses of the atmospheric part of the full Earth system. These efforts in the U.S., Europe, and Japan proved extremely valuable to the research community and decision makers. They have allowed a better understanding of the atmosphere and have been the foundation of numerous important studies of global weather and climate. A comprehensive Earth system analysis would extend the concept of atmospheric reanalysis to the entire geophysical and ecological system. It would include the atmosphere, hydrosphere, cryosphere, biosphere, chemical constituents, aerosols, land surface, and other components of the integrated planetary system as well as the social and economic aspects of ecosystems. The benefits of this type of analysis are significant, providing in near real-time a snapshot of the state of Earth's coupled environmental components. Developing this capacity will prove especially useful for decision support in applications involving complex phenomena, like drought and potential abrupt climate change, for which impacts are not dependent on a single variable but rather on conditions and interactions among numerous physical, biological, and social variables. Integrated Earth system analysis blends diverse data sets together with models to obtain a unified, consistent description of the Earth system and so provides a bridge between observations and predictions.

4.3 Predictive Modeling

The environmental challenges facing the nation require NOAA to take a new approach to assessing the current state of the environment and making predictions about future states. This requires computer models that take into account the interactions among the ocean, the

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atmosphere, the land surface, and chemical and biological processes. Such models have broad potential application for ecosystem forecasting. Some will be predictions of what is likely to happen in a particular location in the short-term (e.g., sea nettle swarms in the Chesapeake Bay, the landfall of harmful algal blooms, beach closing, drinking water quality, the movement of oil spills, and coral reef bleaching events). Others will focus on much longer-term and larger-scale phenomena (e.g. year-to-year variation in fish stocks, extinction risk of endangered species, new invasive species encroachments, rates of habitat restoration, effects of climate change on biota, agricultural systems, and water quality and quantity.)

Ecosystem forecasts predict the impacts of physical, chemical, biological, and human-induced change on ecosystems and their components. Extreme natural events, climate change, land and resource use, pollution, and invasive species are key drivers of ecosystem change that interact across wide time and space scales. Ecosystem forecasts aim to understand, predict, and provide information to mitigate the impacts of these stressors on ecosystems and to manage marine resources. Over the next five years and beyond, NOAA will work with its partners to begin exploiting new, interdisciplinary approaches toward developing a series of fully coupled, physical-biological-chemical models at a range of time and space scales. These approaches will help analyze and predict the state of the atmosphere, ocean, coasts and watersheds, land surface, ecosystems, and the hydrologic and biogeochemical cycles.

Even as NOAA advances its ecosystem modeling capabilities, it will also work to improve its core weather and climate models and forecasts. Particular emphasis will be given to accelerating improvements in forecasting high-impact weather events on 1-14 day time scales. Such improvements will arise from higher resolution models and associated data assimilation schemes that can capture critical small scale physical processes more effectively than present. Emphasis will also be placed on producing ensembles of forecasts to provide users with information about the level of confidence that can be assigned to these forecasts. In addition, the weather and climate research communities are increasingly recognizing that properly representing certain physical processes, like those involving tropical convection, is necessary to improve forecast skill on extended weather and climate time scales. NOAA will encourage the further integration of weather and climate models so they seamlessly represent dynamical and physical processes important to the atmosphere's evolution over days to months to decades and beyond.

In a larger framework, NOAA will develop Earth system models and make projections of how the Earth system will evolve based on understanding the factors that change the radiative forcing of the planet, land and ocean carbon budgets, ocean heat transport, biogeochemical cycling, and other relevant processes. Earth system models simulate these factors to provide products that will enable new capabilities in decision support related to a broad range of policy and management issues dealing with global, regional, and ecosystem change and adaptation. These include issues associated with changing extremes, environmental and human health, land use, sea level rise, and adapting to or mitigating climate change. Ecosystem based management will require a better understanding of the impacts on the habitat of land-based and airborne pollution, the impacts of climate variability and change, and human resource utilization. Earth system models are intended ultimately to provide a unifying framework for this important work.

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5. Overview of NOAA's Mission Goals

NOAA research leads to validated science-based, customer-driven products and services. The desired *outcomes* of these products and services are expressed in the NOAA Strategic Plan and are reproduced in Table 5.1 according to each of NOAA's Mission Goals. Chapters 6 through 9, devoted to each Mission Goal, identify the role research plays in helping NOAA achieve these outcomes. Chapter 10 describes the research in NOAA's Mission Support Goal that enables research in the other Goals. The tools described in the previous chapter—integrated observations, environmental systems analysis, and predictive modeling--buttress research in every Goal. The following chapters describe how these tools are developed and applied in each part of NOAA's research enterprise.

Table 5.1. NOAA's Outcomes by Mission Goal

Mission Goal	Outcomes
Ecosystems	• Healthy and productive coastal and marine ecosystems that benefit society • A well informed public that acts as steward of coastal and marine ecosystems
Climate	• A predictive understanding of the global climate system on time scales of weeks to decades with quantified uncertainties sufficient for making informed and reasoned decisions • Climate-sensitive sectors and the climate-literate public effectively incorporating NOAA's climate products into their plans and decisions
Weather and Water	• Reduced loss of life, injury, and damage to the economy • Better, quicker, and more valuable weather and water information to support improved decisions • Increased customer satisfaction with weather and water information and services
Commerce and Transportation	• Safe, secure, and seamless movement of goods and people in the U.S. transportation system • Environmentally sound development and use of the U.S. transportation system

Performance objectives in NOAA's Strategic Plan have been developed to help evaluate attainment of the outcomes. NOAA's performance objectives are restated in the following chapters, and interim progress toward achieving them is indicated by *research milestones* in timeframes of *0-2 years* and *3-5 years*. In each of the 17 research areas that comprise the Mission Goal plans, research milestones are clearly identified with NOAA's performance objectives. The research milestones are derived from NOAA's FY 2007-2011 program plans and assume adequate funding for their completion. Together, the performance objectives and research milestones will be used to assess NOAA's success toward attaining the outcomes.

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6. Ecosystem Mission Goal: Protect, Restore, and Manage Use of Coastal and Ocean Resources through Ecosystem Approaches to Management

6.1 Introduction

Our nation is home to some of the most richly diverse and unique ocean, coast, and Great Lakes ecosystems on the planet. Each is the site of complex physical, chemical, biological, and social processes that govern, in some cases, vastly productive areas. As populations along our coasts grow and our dependence on natural resources increases, the U.S. economy is inextricably linked to the health of our nation's marine and coastal ecosystems and the goods and services they provide. Yet our knowledge of how they function is limited.

> "Multi-faceted and complex, marine ecosystems…. provide a wealth of benefits to humankind …. Comprehensive, well-focused, interdisciplinary research can provide the information needed to balance competing uses of the marine environment and to better predict impacts of such use…(on) marine ecosystems."
>
> -- *National Ocean Research Priorities Plan: Charting the Course for Ocean Science in the United States for the Next Decade*

Ecosystems are geographically specified systems of organisms (including humans), their environments, and the processes that control their dynamics[1]. NOAA's mission is to effectively and efficiently discover, protect, restore and manage U.S. marine and coastal ecosystems by the application of scientific research, monitoring, and observation. By conducting state-of-the-art ecosystem research, the agency strives to provide scientifically defensible approaches to support protection, restoration, and management of marine and Great Lakes ecosystems.

NOAA's Ecosystem Goal research is guided by the near-term and long-term priorities identified in the National Ocean Research Priorities Plan, as well as by a variety of legislative mandates. NOAA's ecosystem-related programs are responsible for implementing and complying with over 90 different laws, including the reauthorized Magnuson-Stevens Fishery Conservation and Management Act, as well as those covering coastal management, endangered species, invasive species, and marine mammals.

> Sound ecosystem management requires scientifically-based information on ecosystem condition, the causes and consequences of that condition, forecasts of their future condition(s), and the costs and benefits of different management actions to respond to that condition.

Ecosystem Approaches to Management

NOAA's research priorities over the next five years will support an ecosystem approach to management (EAM). EAM links resource management with the biotic and abiotic interactions affecting the resource of interest, rather than considering single issues in isolation. This system of management also considers human activities, their benefits, and their potential impacts to the environment. Instead of developing a management plan for one issue or based on political boundaries, EAM focuses on the multiple activities occurring within specific ecosystem boundaries.

[1] ***New Priorities for the 21st Century –*** *NOAA Strategic Plan*, 2006-2011, P.3.

An ecosystem approach to management of marine and coastal resources requires managers to balance societal, economic, and environmental needs with resource usage, while preserving ecosystem biodiversity. Resource sustainability necessitates that biological and economic productivity be maintained without foreclosing options for future generations.

> *Success Story*: The recent transition of the NOAA Harmful Algal Bloom Forecast System for the Gulf of Mexico from research to operations illustrates the progress in ecological prediction at NOAA. Other examples include now-casting the presence of sea nettles, a stinging jellyfish in Chesapeake Bay, the ability to forecast ecosystem impacts to sea level rise, and the amount of oyster mortality due to the effect of changes in salinity on the abundance of one of its major predators, the oyster drill.

As a first step towards implementing an ecosystem approach to management, NOAA's Ecosystem Goal activities are organized to include 8 regional ecosystems adjacent to the US coasts (Northeast Shelf, Southeast Shelf, Caribbean, Gulf of Mexico, Great Lakes, California Current, Alaska, and Pacific Islands), but also recognize science and management links to other international marine ecosystems, such as the Antarctic. Special designated marine protected areas and marine sanctuaries also have specific ecosystem research requirements that are linked to their respective regional ecosystem. NOAA supports regional approaches to science and management through the development of the integrated ocean observing system that provides the data for integrated ecosystem assessments and forecasts, as well as implementation of management strategies at regional scales. In the past few years, several external drivers have called for increased NOAA attention on EAM[2] in the context of current statutory or trust authorities.

6.2 Developing and Applying the Research Tools

> *Success Story:* PaCOOS is a NOAA-wide effort to develop the ecological observing system for the California Current regional ecosystem that stretches the entire US West Coast. Extensive collaboration is required with federal and state agencies, academic institutions and the 3 Regional Associations within the region. Products under development include ecological forecasts and an Integrated Ecosystem Assessment as part of an EAM.

The mechanisms for NOAA's move towards EAM over the next five years are integrated ecosystems assessments and forecasts. These mechanisms are supported by the Integrated Ocean Observing System (IOOS), including data collection and analyses as well as predictive modeling. Because our knowledge of ecosystem structure and function is very incomplete, an observing backbone is being implemented that will collect ecological and oceanographic measurements that elucidate processes acting across regional ecosystems. IOOS can provide the data and forecasting models for implementing EAM through ongoing and rapid assessment of coastal conditions and through timely detection, prediction, and notification of ecosystem changes. Research priorities supported by IOOS are to collect ecosystem observations (physical, biological, chemical and socio-economic) that support integrated ecosystem assessments, and to develop forecasts at the regional ecosystem scale. Specific ecological and human health threats to be targeted in the next five years include climate and fishing effects on ecosystems, harmful algal blooms (HABs), invasive species, water quality and habitat degradation, and infection and disease (pathogens).

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[2] U.S. Ocean Action Plan.
External Ecosystem Task Team Report to NOAA's Science Advisory Board, *Evolving an Ecosystem Approach to Science and Management Throughout NOAA and its Partners*, July 2006, P. 8.
House/Senate bills for Magnuson-Stevens Reauthorization bills, 2006.

Ecological observing and research rely on a suite of existing and new platforms, technologies, and experimental approaches to improve our understanding and management of coastal and marine resources. Ship and aircraft surveys will remain critical platforms for ecological observing and research. In addition, enhanced and new platforms such as Autonomous Underwater Vehicles (AUVs), gliders and seafloor observing systems will be modified and developed to improve ecological discovery, observing, and research needs. New technologies such as autonomous biological and chemical sensors, acoustic tagging, and others, are becoming more robust and therefore available for ecological research. Development for new platforms and technologies will require new collaborations with external partners with engineering expertise.

6.3 Outcomes and Performance Objectives

Table 6.1. Ecosystem Goal Level Outcomes and Performance Objectives from the FY2006 - FY2011 NOAA Strategic Plan

Outcomes	Performance Objectives
Healthy and productive coastal and marine ecosystems that benefit society A well informed public that acts as a steward of coastal and marine ecosystems	• Increase number of fish stocks managed at sustainable levels • Increase number of protected species that reach stable or increasing population levels • Increase number of regional coastal and marine ecosystems delineated with approved indicators of ecological health and socioeconomic benefits that are monitored and understood • Increase number of invasive species populations eradicated, contained, or mitigated • Increase number of habitat acres conserved or restored • Increase portion of population that is knowledgeable of and acting as stewards for coastal and marine ecosystem issues • Increase environmentally sound aquaculture production • Increase number of coastal communities incorporating ecosystem and sustainable development principles into planning and management.

6.4 Research Areas

NOAA's ecosystem Research Areas for the next five years address the following five themes of the Ecosystem Goal: 1) support collaborative approaches to science and management at the regional level, 2) understand the impacts of climate on ecosystems, 3) enhance social and ecological resilience to hazards, 4) protect marine and coastal resource integrity and security, and 5) develop more robust ecosystem modeling and integrated assessment capability to serve current and future management information needs. These Research Areas are also common with many of the 20 research priorities identified in the National Ocean Research Priorities Plan[3].

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[3] Joint Subcommittee on Ocean Research and Technology. *Charting the Course for Ocean Science in the United States: Research Priorities: National Ocean Research Priorities Plan,* 2006.

6.4.1 Advancing understanding of ecosystems to improve resource management

NOAA's goals for resource management rely on research to understand fundamental processes. This research is a major contributor to nearly every Program within NOAA's Ecosystem Goal. Two NOAA Programs focus exclusively on research and observation needs of the other six Programs within the Goal: NOAA's Ecosystem Research Program and the Ecosystem Observations Program.

The *NOAA Ecosystem Research Program (ERP)* provides scientific information and tools necessary for ecosystem management. ERP's integrated ecosystem assessments and research focus on natural and anthropogenic factors that affect coastal, Great Lakes, and ocean ecosystems. Priority research areas for the next five years include:

- Increase understanding of ecosystem composition, structure, functioning, and variability
- Conduct comprehensive process studies to understand mechanisms producing patterns and to define ranges for key physical and biological parameters within ecosystem models
- Understand large-scale ecosystem drivers and ecological communities, including interactions among species, the physical environment, evolutionary history, and the "assembly rules" by which ecosystems are formed
- Establish ecosystem indicators and ascertain what, if any, thresholds and breakpoints within ecosystems
- Study the potential of geologic features to generate coastal earthquakes, tsunamis, and greenhouse gases and the extent to which they create new unique ecosystems
- Develop a suite of tools for ecosystem forecasting that improves ecosystem understanding, decision-making and reduces risks to ecosystem and human health

Fig. 6.1. NOAA's Ecosystem Observation Program employs the NOAA Fleet to collect a variety of data. These ships are among the most advanced research vessels in the world, including exacting quietness standards to avoid influencing the survey results by disturbing the fish and mammals being studied.

The *NOAA Ecosystem Observations Program (EOP)* provides observations and assessments, and ecological forecasts. These products are used in assessments of fish stock and living marine resources (marine mammals and sea turtles), the condition of marine protected areas, development of ecological indicators, the monitoring coastal contaminants, and to identify information gaps in the understanding of the biology, ecology and life history of species. Priority research activities include:

- Expand monitoring of commercial and recreational fisheries by investing in improved technologies, sampling designs and reporting and data management
- Generate and manage data and information necessary for conducting Integrated Ecosystem Assessments (IEAs) and risk analyses
- Improve observing system networks to advance understanding of the linkages between ecosystem processes and the abundance, distribution, and biodiversity of species
- Develop technologies to advance areas such as sampling for bottom typing and seabed classification, video mosaic techniques, and relating biological distributions to geological features

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Six other science-based Programs within the Ecosystem Goal have basic research requirements to carry out their management missions. Some specific understanding needs are addressed within these Programs themselves.

The *NOAA Aquaculture Program* supports production and enhancement technology development to increase seafood production and replenish depleted species in an environmentally and economically responsible way. Research foci include determining methods to culture species and to monitor and evaluate results, undertaking economic and environmental analyses, identifying criteria for siting aquaculture facilities, and replenishing rebuilding of depleted resources. Priority research activities include:

- Study aquacultured species' impact on structure/function of surrounding ecosystems
- Document impacts on the genetic diversity of wild stocks and the release of pathogens on native populations from aquaculture operations
- Investigate transition from fish feed to vegetable feed

The *NOAA Coastal and Marine Resources Program* supports resource managers to protect, restore, and manage ocean and coastal resources through ecosystem-based management. Research foci include implementing place-based management restoration, and protection programs in partnership and coordination with extramural partners. Priority research activities include:

- Characterize the biological, chemical, physical, and ecological conditions of coastal and marine ecosystems to quantify change due to natural and anthropogenic stressors
- Improve understanding of human interactions with coastal and marine ecosystems
- Document influence of anthropogenic stressors on biodiversity and population dynamics of coastal and marine ecosystems
- Conduct studies on 'spillover effects' (export of larvae and fish; distribution of fishing effort) from marine protected areas to adjacent areas

The *NOAA Coral Program* works to reduce the impacts of key threats to coral reefs. Research foci include understanding the impacts of climate change and coral disease, fisheries population dynamics and ecology, restoration and mitigation approaches, effects of anthropogenic stressors on benthic invertebrates, impacts of invasive species, and evaluating management actions and strategies. Priority research activities include:

- Investigate cascading effects of overfishing (e.g., reduced predator and herbivore abundances and sizes) on ecosystem functions
- Study coldwater corals: life stages of fish present around them and status as essential fish habitat
- Improve understanding of response to climate change

> *Success Story*: In 2005, NOAA scientists determined population levels for 206 fish stocks and multi-species groupings known as complexes. Of these, 152 (74 percent) were not overfished. NOAA scientists also determined the harvest rates for 237 stocks and found that 192 (81 percent) were not subject to overfishing. In 2006, NOAA was mandated by Congress to end overfishing by 2011.

The *NOAA Fisheries Management Program* ensures that fisheries are maintained at sustainable and productive levels. Research foci will improve the understanding of the cascading effects of reduced predator and herbivore abundances and sizes, the societal drivers of overfishing, the efficacy of management actions, gear impacts, and developing new technologies. Priority research activities include:

- Assess socioeconomic impacts of existing and proposed fisheries management plans that affect ecosystems, and likewise, investigate the drivers of overfishing

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- Determine ecological factors that facilitate invasive species competition with native species
- Improve knowledge of forcing factors that affect regional fish recruitment/production

The *NOAA Habitat Program* protects coastal, marine, and Great Lakes habitat, improves the quality, and increases the quantity of restored habitats. Research foci includes developing techniques to achieve successful protection and restoration, determining the pathways and control of marine invasive species, studying the linkages between habitats and fisheries productivity, and implementing projects that help restore habitat value and function. Priority research activities include:

- Study links between habitat decline and condition of habitat-dependent fisheries
- Map and characterize habitats and their condition
- Advance biomedical and commercial applications of marine natural products
- Develop technologies to detect, prevent, and remediate coastal pollution and habitat degradation

The *NOAA Protected Species Program* is responsible for the protection and recovery of threatened and endangered marine and anadromous species, and for the conservation of most marine mammals protected by law. Research foci include identifying threats causing the decline of protected species populations (primarily various populations of marine mammals, sea turtles, and salmon), increasing the knowledge of the basic biology and ecology of protected species with the ultimate purpose of stabilizing and recovering populations. Priority research activities include:

- Assess factors affecting protected species and successful remediation/management strategies for ensuring their populations
- Determine functional role of a protected species in an ecosystem context

Table 6.2. Selected Research Milestones and Performance Objectives for Advancing Understanding of Ecosystems to Improve Resource Management

<table>
<tr><td colspan="2">Research Area: Advancing understanding of ecosystems to improve resource management</td></tr>
<tr><td colspan="2">Performance Objective: Increase number of fish stocks managed at sustainable levels</td></tr>
<tr><td>0-2 Year Milestones</td><td>Measure the natural scales of variability regarding physical-biological coupling, food web dynamics and ecosystem production in selected ecosystems.</td></tr>
<tr><td colspan="2">Performance Objective: Increase number of regional coastal and marine ecosystems delineated with approved indicators of ecological health and socioeconomic benefits that are monitored and understood</td></tr>
<tr><td>0-2 Year Milestones</td><td>Confirm an IEA framework; synthesize existing data, information and format for integrated analysis; and initiate modeling in support of IEAs.</td></tr>
<tr><td>3-5 Year Milestones</td><td>Produce at least two integrated ecosystem assessments that evaluate the ecological response to various anthropogenic stressors.</td></tr>
<tr><td colspan="2">Performance Objective: Increase number of protected species that reach stable or increasing population levels</td></tr>
<tr><td rowspan="3">3-5 Year Milestones</td><td>Identify ecosystem carrying capacity for critical protected species as a step in providing more efficient recovery strategies.</td></tr>
<tr><td>Develop multiple GIS layers and one best practices manual as foundation for improved coordination between Federal action agencies and ocean energy industry.</td></tr>
<tr><td>Estimate ambient noise budgets in at least one regional ecosystem by characterizing the nominal acoustic environments.</td></tr>
<tr><td colspan="2">Performance Objective: Increase number of habitat acres conserved or restored</td></tr>
<tr><td>0-2 Year Milestones</td><td>Identify, map and evaluate existing and restorable habitat and key habitat functions; evaluate the function/health of habitat.</td></tr>
<tr><td colspan="2">Performance Objective: Increase environmentally sound aquaculture production</td></tr>
</table>

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0-2 Year Milestones	Develop environmentally sound aquaculture technologies for marine species.

6.4.2 Exploring our oceans

NOAA's ocean exploration effort conducts bold and innovative investigations of the oceans for the purpose of discovery, new knowledge and insight, identification of new resources with societal and economic benefits, and as a vehicle to promote ocean literacy. Ocean exploration emphasizes unknown or poorly known areas, in addition to exploring changes over time. By virtue of this emphasis, exploration can aid in understanding and better predicting changes in the earth's environment (e.g., global carbon cycle, climate and ecosystems, energy mass balance) and managing resources responsibly (i.e., diversity, distribution and abundance).

A dedicated ocean exploration vessel (the *Okeanos Explorer*), will significantly increase the number of multi-disciplinary NOAA explorations beginning in FY08. Peer-reviewed proposals and community and stakeholder workshops will determine the ship's expeditions and cruise track. The ship will be exploring new areas and will characterize the environmental setting and sample, as appropriate, for new living and non-living resources. The work conducted on the *Okeanos Explorer* is intended to complement, not replace the multi-disciplinary expeditions the program supports using other NOAA and UNOLS ships.

In addition to the U.S. EEZ, the 95% of the unknown ocean area includes approximately, 50,000 km of mid-ocean ridge crest, 10,000 km of deep ocean trenches, 100,000+ seamounts and the volume of the ocean, representing 99% of the earths' bio-sphere. Technological advances associated with Human Occupied and Remotely Operated Vehicles have greatly extended our reach; however, they are not broad-area search vehicles. Development and application of complementary exploration methods and systems, including remote sensing technology, will be pursued to make significant progress toward reducing the 95% unknown ocean.

Priority research activities include:

- Map and characterize poorly known key features and habitats of economic, hazardous, scientific or cultural importance in support of integrated ecosystem assessments
- Describe poorly-known or unknown communities of organisms displaying novel relationships with their environment (e.g., vent/seep communities), as well as poorly-known or unknown physical or chemical processes with global implications (e.g., deep ocean currents, chemical or greenhouse gas sources);
- Discover and describe new species and new resources, both living and non-living (e.g., energy, minerals, food, bio-products);
- Design, develop and utilize new methodologies and probes, sensors and systems that will increase the pace, efficiency and scope at which living and non-living resources and processes are discovered and to rapidly improve our understanding of how oceans respond to change
- Discover, investigate and inventory shipwrecks, aircraft and submerged landscape projects and investigate significant maritime heritage projects

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Table 6.3. Selected Research Milestones and Performance Objectives for Exploring Our Oceans

Research Area: Exploring our oceans	
Performance Objective: Increase portion of population that is knowledgeable of and acting as stewards for coastal and marine ecosystem issues	
0-2 Year Milestones	Use satellite tele-presence capability on at least two missions to make scientists, advocates, teachers, and students ashore, virtual members of scientist-explorer teams at sea on NOAA's ship for ocean exploration.
	Submit data, findings and results from all OE projects in FY07-11 to appropriate on-line repositories and archives.
	Raise student, teacher, and public awareness and stewardship of the oceans through a significant web presence, curriculum development, and signature expeditions.
3-5 Year Milestones	Conduct tandem operations of the Okeanos Explorer and autonomous underwater vehicles to increase the efficiency, pace and scope of ship-based underwater survey/reconnaissance efforts.
	Submit data, findings and results from all OE projects in FY07-11 to appropriate on-line repositories and archives.
Performance Objective: Increase number of coastal communities incorporating ecosystem and sustainable development principles into planning and management.	
3-5 Year Milestones	Discover, characterize and determine the extent of unique and significant habitat within at least one of the Nation's existing marine protected areas and monuments and within the EEZ for potential establishment of such areas.

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6.4.3 Forecasting ecosystem events

Ecological forecasting is perhaps the most complex modeling challenge that NOAA faces. In much the same way that weather and economic forecasts can help society plan for future contingencies, ecological forecasts can help environmental managers evaluate alternative management scenarios and take appropriate actions to better manage our Nation's coastal resources. Ecological forecasts use our basic scientific knowledge and understanding of physical, chemical, biological, and human-induced changes to predict impacts on ecosystems and their components such as harmful algal blooms, water quality, and fish recruitment. They are tools to help managers understand and answer questions about the ocean, coastal, and Great Lakes and coastal environments, and to provide a bridge between research science and governmental policy. These ecological predictions do not guarantee what is to come; instead, they offer scientifically based estimates and scenarios of what is likely to occur.

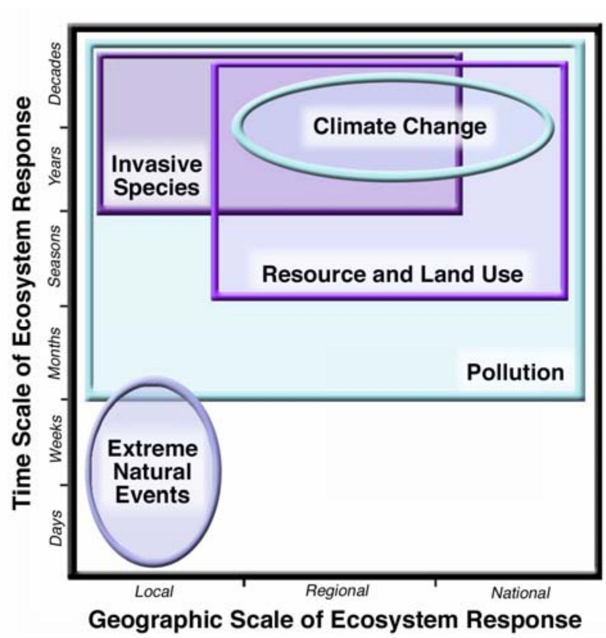

Fig. 6.2. Time/Space Scale of Ecosystem Response: Ecosystem responses vary depending on inputs that strain them, and they play out in scales from hours to decades and from local to global.

Over the next five years and beyond, NOAA will conduct research toward predicting the effects that extreme natural events, climate change, land and resource use, pollution, invasive species, fisheries impacts, coral bleaching have on coastal and marine ecosystems. We will do this by 1) developing and implementing models that quantitatively capture the relationship between the biological and physical environment and ecosystem composition, structure, and function, and 2) adding data to these models from the Integrated Ocean Observing System (IOOS). In some cases, models will integrate the information needed to investigate, predict and manage a coastal and marine ecosystem.

Future priority research activities include:

- Identify key indicators of both ecosystem function and human influence, with the aid of models, that need to be measured in order to characterize an ecosystem
- Define time and space scales needed to capture fundamental physical and biological drivers required for forecasts
- Estimate natural scales of variability regarding physical-biological coupling, food web dynamics and ecosystem production
- Understand how multiple stressors interact to affect ecosystem structure and function
- Develop fully integrated, spatially explicit, coupled hydrodynamic and biological models with links to meteorological, watershed and higher trophic level models on key scales
- Evaluate accuracy of model forecasts and assess impact of management decisions on resources and habitat quality
- Transition validated ecological prediction systems from research to operations

Table 6.4. Selected Research Milestones and Performance Objectives for Forecasting Ecosystem Events

Research Area: Forecasting ecosystem events	
Performance Objective: Increase number of coastal communities incorporating ecosystem and sustainable development principles into planning and management.	
0-2 Year Milestones	Forecast the ecological effects of sea level rise and climate change.
	Define the primary forcing factors and time and space scales that affect water quality and quantity for selected ocean, coastal and Great Lakes regions.
3-5 Year Milestones	Forecast the ecological effects of varying weather patterns and extreme physical events.
Performance Objective: Increase number of regional coastal and marine ecosystems delineated with approved indicators of ecological health and socioeconomic benefits that are monitored and understood	
0-2 Year Milestones	Define the primary forcing factors and time and space scales that cause HABs and anoxia for selected coastal, ocean, and Great Lakes regions.
	Identify sentinel species and other proxies for early detection of pathogen and microbial contaminants.
3-5 Year Milestones	Determine the effectiveness of at least two marine reserves in rebuilding and sustaining fishery stocks.
Performance Objective: Increase number of fish stocks managed at sustainable levels	
3-5 Year Milestones	Define the primary forcing factors and time and space scales that affect fish recruitment and fisheries production for selected coastal and Great Lakes regions.

6.4.4 Developing integrated ecosystem assessments and scenarios, and building capacity to support regional management

As more predictive capabilities become a part of a larger management ‘toolbox’, policy makers and managers will be able to prepare and quickly respond to environmental changes. Scientific

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research into methods to integrate environmental information is critical to improving our predictive and management capabilities.

Integrated ecosystem assessment is an area of considerable focus for NOAA in 2007-2011. An IEA is a comprehensive account of an ecosystem's condition, stressors, and drivers, and the potential for change in response to management options. It provides a "big picture" understanding of an ecosystem, its many components and functions (including humans and human activities), how they interact with each other and change over time, as well as how these changes affect lives, livelihoods, and quality of life. Research in the next five years into the components of IEA structure and how various data and predictive information may be integrated will allow us to produce IEAs that will address an enormous array of environmental management challenges.

Scenario development is a modeling technique that can be used to simulate "futures" for potential impacts on aquatic and other natural resources. Scenarios can serve as a sequence of 'what if?' situations in which a set of hypothetical environmental conditions are assumed to explore the implications of changes to the ecosystem. Scenarios are used as anticipatory planning and communication tools to explore uncertain futures. The difference between scenario development and forecasts is that scenarios do not aim to predict, but are designed to give representations of possible futures. They can be used to compare and contrast the potential influences of particular biophysical, social, economic, cultural, or political attributes of a system. They can also be used to explore differences between current and future conditions and identify possible outcomes of various policy or management decisions.

> *Success Story:* A forecasting model developed in 2005 uses a scenario planning framework to evaluate risks to blue crab populations and makes recommendations to fishery managers. The testing of 'what if' scenarios will help determine the impact of changes in water quality and fishing pressure on blue crab populations. Managers can compare the relative benefits of reducing the number of traps or closing areas, as well as economic impacts on the fishery of a disease outbreak, a tropical storm or an oil spill.

Scenarios that link human activities and natural resource conditions and alternative ecosystem-based approaches to management can be developed to inform decision-making for human dominated ecosystems. For example, known effects of coastal urbanization and related land cover change variables (e.g., forest fragmentation, nonpoint source pollution, percent impervious surface) can be combined with variables for coastal or near shore systems (e.g., riparian ecotones, submerged aquatic vegetation (SAV) beds, coral reefs) to depict relationships between various human activities, ecological functions (e.g., primary productivity), and ecosystem attribute presence/quality (e.g., biodiversity). This approach allows testing of 'what if' questions that reflect what *should* (or ought to) be and what is realistic, logical, or expected given social, managerial, budgetary, or political realities. Manipulations (or subsequent runs) of such scenarios can identify priority conservation targets, ecosystem attribute threats or vulnerabilities, and plausible planning and management prescriptions.

Other scenario research activities support ecologically sound aquaculture; promote understanding and introduction of invasive species; development of technologies, including marine biotechnology, to aid coastal zone management; promote understanding of how individuals and groups behave under regulations and differing ecosystem management and governance arrangements.

Priority research activities include:

- Develop integrated ecosystem assessments

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- Develop risk/value evaluations of alternative ecosystem-based management strategies using assessments and ecological forecasts

Table 6.5. Selected Research Milestones and Performance Objectives for Developing Integrated Ecosystem Assessments and Scenarios, and Building Capacity to Support Regional Management

Research Area: Develop integrated ecosystem assessments and scenarios, and building capacity to support regional management	
Performance Objective: Increase number of invasive species populations eradicated, contained, or mitigated	
0-2 Year Milestones	Transition of two tools or best practices to prevent introduction of invasive species into coastal environments from other than “no-ballast-on-board” ships in the Great Lakes.
Performance Objective: Increase number of regional coastal and marine ecosystems delineated with approved indicators of ecological health and socioeconomic benefits that are monitored and understood	
0-2 Year Milestones	Three regional workshops with stakeholders to identify needs and information gaps for the California Current, Northeast, and Alaska Integrated Ecosystem Assessments.
3-5 Year Milestones	Report on the evaluation of the risk/benefit of ecosystem-based management strategies (i.e. integrated ecosystem assessments) in the California Current.
Performance Objective: Increase number of protected species that reach stable or increasing population levels	
0-2 Year Milestones	Research to improve our understanding of the factors affecting threatened species and the potential success of alternative remediation/management strategies.
Performance Objective: Increase portion of population that is knowledgeable of and acting as stewards for coastal and marine ecosystem issues	
3-5 Year Milestones	Expand extension and education approaches to provide scientific information in advance of actions and regulations and to assist NOAA in fostering increased under-standing and partnerships among fishers, conservation and environmental groups, coastal use community, and scientists.
Performance Objective: Increase number of coastal communities incorporating ecosystem and sustainable development principles into planning and management.	
3-5 Year Milestones	At least a 25% increase in NOAA’s applied, non-economics social science research capacity to support increased research focus on social, cultural, and policy aspects of ecosystem-based approaches to management.

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7. Climate Mission Goal: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

7.1 Introduction

As we move into the 21st Century, society will continue to face major challenges in which the influence of climate will be a fundamental factor. Global warming scenarios suggest an intensification of hurricanes and a possible shift westward of storm activity, increasing the possibility of more U.S. landfalls. Research into droughts in the West over the past 1000 years shows more mega droughts in the past, suggesting that the recent multi-year drought in the West can perhaps become more the norm. Modeling results for the Fourth IPCC Assessment indicate that in the future mid-latitudes might become drier. Results also suggest that the Arctic in summer may become ice free this century. Reducing climate-related uncertainties in policy and decision making can be valued at more than $100 billion for the United States alone, and relatively small increases in accuracy can yield substantial benefits.

> *Gaps in our understanding of climatic variations, particularly intra-seasonal and interannual trends, hinder efforts to address important societal issues including drought, human health, agriculture, sustainable living marine resources, and urban and coastal impacts from climate change.*
>
> ***NOAA Annual Guidance Memorandum FY08***

In the next five years and beyond, NOAA's climate research priorities and outcomes will lead to science-based climate information services as envisioned by the U.S. Climate Change Science Program and as needed to meet NOAA's commitments to deliver information products to the nation. The Climate Goal will strive toward an integrated approach to environmental information and modeling in support of the climate-related aspects of the US Integrated Earth Observation System (IEOS) Strategic Plan. In response to the Ocean Research Priorities Plan, the Climate Goal will enhance its ocean focus to provide understanding of climate impacts on ecosystems These focus areas will increase the progress of the Climate Goal to integrate observations, data management, and modeling, as well as provide a new suite of environmental products and services. The Climate Goal must maintain and augment its current capabilities to meet new challenges.

> *The U.S. Climate Change Science Program, with NOAA as lead, issued the first of 21 Synthesis and Assessment S&A Products, titled "Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences". This report improves our understanding of climate change and human influences on temperature trends.*

Key to more sustained climate observations will be NOAA's role in the development and enhancement of global integrated observing systems as part of the international GEOSS. The results of these activities will enhance and directly support both national and international assessments of the climate system (e.g., CCSP synthesis products IPCC Assessment Reports, Assessment Reports of the U.N. Montreal Protocol on the Ozone Layer), as well as contribute to an end-to-end climate program developing and delivering critical climate services to the nation.

The ultimate success of climate research within NOAA depends on close collaboration with universities, state and other federal agencies, non-governmental organizations, private industry, and international partners. NOAA climate research is coordinated nationally through the CCSP and internationally through a variety of bilateral and multilateral arrangements. The program is

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managed through routine development, modification, and assessment of goal and program performance objectives and research milestones.

Stakeholders and customers for climate research range from decision makers, resource managers, and policy makers dealing with global, regional, and local issues in most sectors: energy, transportation, industry, land use, water, agriculture, commerce, environmental organizations, the general public, other federal agencies, and other researchers both internal and external to the federal government.

7.2 Developing and Applying the Research Tools

Reliable and timely access to climate data and information are essential to improved understanding of key physical processes of the climate system, improving climate prediction and projection models, regularly producing integrated analyses of the climate system, and reporting on the causes and consequences of observed climate variability and extreme events. NOAA envisions scientific data stewardship as an end-to-end system that includes: systematic collection of oceanic and atmospheric observations; data processing and reprocessing to produce climate-quality data; observing system performance monitoring; long-term archiving; and reliable and timely access to data. These are the key elements needed to respond to the scientific information needs of climate researchers.

Vital to all research is the ability to transfer understanding and knowledge to products and services that are relevant, routinely produced operationally, and available to users—the transition of research to practical operational support. This requires close working relationships among users, t operational service providers, and the research community. Enhancing NOAA's climate services will require NOAA-funded research directed towards improvements and extensions of operational forecasts and data products on intraseasonal to interannual timescales associated with resource management and long-term health and environmental impacts. The new product suites will ultimately include ecosystem and enhanced air and water quality forecasts. These research efforts are intended to further research-based integration between studies of the climate system, including socio-economic components and evolving informational and educational needs of decision makers in climate sensitive sectors.

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7.3 Outcomes and Performance Objectives

Table 7.1. Climate Goal Outcomes and Performance Objectives from the FY2006 – FY2011 NOAA Strategic Plan

Outcomes	Performance Objectives
A predictive understanding of the global climate system on time scales of weeks to decades with quantified uncertainties sufficient for making informed and reasoned decisions Climate-sensitive sectors and a climate-literate public effectively incorporating NOAA's climate products into their plans and decisions	• Describe and understand the state of the climate system through integrated observations, analysis, and data stewardship • Reduce uncertainty in climate projections through timely information on the forcing and feedbacks contributing to changes in the Earth's climate. • Improve climate predictive capability from weeks to decades, with an increased range of applicability for management and policy decisions • Understand and predict the consequences of climate variability and change on marine ecosystems • Increase number and use of climate products and services to enhance public and private sector decision making

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7.4 Research Areas

Research activities and associated research milestones are described below in each of five research areas. These research areas parallel the structure of the NOAA climate program.

7.4.1 Develop an integrated global observation and data management system for routine delivery of information, including attribution of the state of the climate

NOAA is providing leadership in building an integrated global climate observing network. This integrated global observing system is the foundation for research critical to understanding the Earth's climate system, improving climate predictions at global and regional scales, and monitoring current climate variations and placing them into historical perspective. Reliable and timely access to climate data and information is essential to improved understanding of key physical processes of the climate system, improving climate prediction and projection models, and regularly producing integrated analyses of the climate system and reporting on the causes and consequences of observed climate variability and extreme events. Data and analysis produced from the climate observing network benefits virtually every sector of the nation's economy. Through these activities, NOAA contributes to the national and global objectives outlined in the Strategic Plan for the Climate Change Science Program (CCSP), U.S. Integrated Earth Observations System (IEOS) Strategic Plan, and the Global Earth Observation System of Systems 10-Year Implementation Plan.

During the next five years, NOAA's climate goal will focus on improving the utility of its observations by integrating climate observations, enhancing data management, and analyzing data derived from these observing systems for improved integrated information products. In addition, continued transition of research to applications will be identified and implemented.

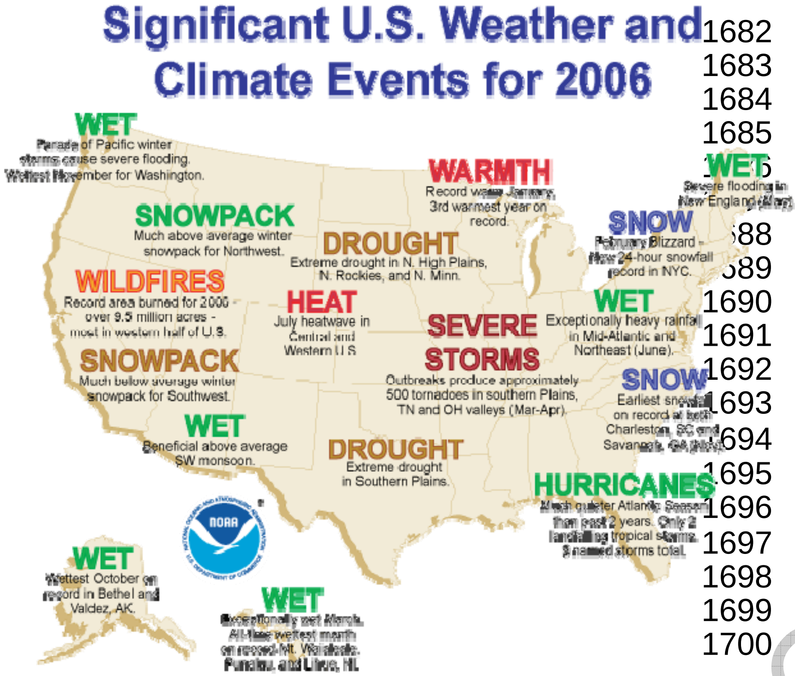

Fig7.1. The National Climatic Data Center (NCDC) in collaboration with other NOAA labs and centers produce maps such as this showing significant US weather and climate events for 2005 on a regional and global scale using weather and climate data collected throughout the year.

Examples of future work include using the TAO transition to evaluate the feasibility of transitioning other ocean observations from research to operations and evaluating maturing research capabilities at NASA for transition to NOAA. These are the key elements needed to respond to the scientific information needs of climate researchers.

Priority research activities in the next five years include:

- Completing the ocean and Arctic observing systems, and integrating surface and upper air measurements.
- Developing a scientific data stewardship and observing system integration and optimization process that will enable NOAA to identify and implement the most cost-effective observations and improved observing systems.
- Collecting and delivering regular, systematic, and reliable climate data and information—with rigorous scientific standards and easy data access by customers—that document and describe the current and evolving state of the climate system through the development of integrated observing systems.
- Conducting research in data assimilation—using data from both current and future advanced satellite systems and in situ observations—to provide new products and measurements that will expand understanding of the climate system.
- Producing reference data sets that provide improved climate information; using these data sets to develop integrated historical analyses of the global climate system through integration of all reference data sets into state-of-the-science global climate models, and using the integrated analysis to carry out detection and attribution studies that link observed climate changes (including changes in extreme events) and climate extremes to specific climate forcing and feedbacks.
- Conducting observational, diagnostic, and modeling research to improve understanding of physical mechanisms and processes of climate variability and predictability that will lead to improved climate models and climate predictions.

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Table 7.2. Selected Research Milestones and Performance Objectives for Integrated Global Observation and Data Management System

Research Area: Develop an integrated global observation and data management system for routine delivery of information, including attribution of the state of the climate	
Performance Objective: Describe and understand the state of the climate system through integrated observations, analysis, and data stewardship	
0-2 Year Milestones	Implement observation and information component of the National Integrated Drought Information System (NIDIS). Examples are to deploy Soil Sensors at U.S. Climate Reference Network (USCRN) sites in support of NIDIS and establish a U.S. NIDIS Portal to provide a drought early warning system from county to national scale.
	Delivery of CCSP Synthesis and Assessment Products on reanalysis of historical data, climate extremes and abrupt climate change.
3-5 Year Milestones	Implement a prototype for routine nowcasting capability for the Atlantic Meridional Overturning Circulation (MOC) and implement a prototype system for decadal outlooks in MOC variations.
	Complete components of the Ocean Observing System for Climate

The above activities support a broad spectrum of customers, both nationally and internationally. Users of climate data and information include operational weather and climate centers, resource managers and policy makers at all levels of government, end users (private sector and general public), and the worldwide scientific research community.

Major research objectives described in this research area are long-term goals. While significant achievements are expected within five years, most of the objectives—for example the integrated global climate observing system-- will take longer to complete. Longer-term research efforts will focus on the development of integrated global climate models and analyses at greater resolution, as well as on an improved understanding of decadal variability and the role of atmospheric chemistry in global climate.

7.4.2 Document and understand changes in climate forcings and feedbacks, thereby reducing uncertainty in climate projections

The focus of this research area is to better quantify the information on atmospheric composition, their influence on energy budget, and feedbacks that contribute to changes in Earth's climate. Specifically, NOAA seeks to provide the understanding needed to link emissions of climate-relevant compounds to the radiative forcing of climate change for science-based decision support.

The Climate Forcing Program is providing research 1) to understand oceanic and atmospheric processes, both natural and human-related, that affect carbon dioxide (CO_2) trends, 2) to quantify the climate roles of the radiatively important trace atmospheric species such as fine particles (aerosols), ozone, and chemically active greenhouse gases, and 3) to understand and assess stratospheric ozone depletion. Research activity 1) may be directly applied to climate projection and to policy decisions regarding carbon management that are related to limiting unwanted effects of future climate change, while research activity 2) provides timely and adequate information needed to broaden the suite of non-carbon options for addressing changes in climate forcing, especially in the next few decades.

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This research is characterized by a four-element, integrated approach:

- Monitoring the global abundances and trends of the greenhouse gases and aerosols, including the oceanic and atmospheric inventories of CO_2, and the fluxes between the terrestrial oceanic and atmospheric carbon reservoirs, thereby providing insight into the highly variable terrestrial carbon sink and systematic changes in ocean sequestration.
- Conducting laboratory and field studies of (1) the oceanic and terrestrial processes that control the natural emissions and uptake processes in the global carbon cycle, and (2) the climate properties of aerosols, tropospheric ozone, and ozone-layer depletion.
- Contributing toward the incorporation of this understanding into predictive models and evaluating the capabilities by comparing "hindcasts" to measured trends and by testing the ability to represent the observed changes of atmospheric constituents.
- Delivering peer-reviewed information products, co-identified with stakeholders that assess the state of understanding of climate-change forcing.

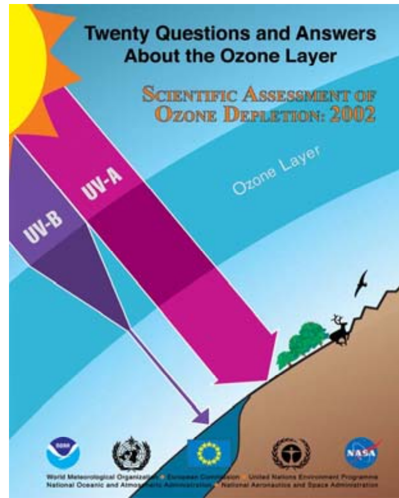

Fig7.2. The Scientific Assessment of Ozone Depletion document is produced every four years by the Ozone Assessment Panel as part of the U.N Montréal Protocol. NOAA scientists have been involved in the production of this assessment since its inception, making the document a major contribution to NOAA's portfolio of climate science products.

NOAA's climate forcing research supports both national and international assessments of the climate system, e.g., the synthesis and assessment products of the CCSP, the assessment reports of the IPCC, and the reports to the U.N. Montreal Protocol on the ozone layer. Such science-based assessments and scenarios provide (1) tools for better management of carbon- and non-carbon-based climate-forcing emissions, (2) a suite of choices for both air quality and the alteration of climate forcing in the near term, and (3) longer-term assessments of strategies for managing climate-forcing emissions over the longer term.

Table 7.3. Selected Research Milestones and Performance Objectives for Documenting and Understanding Changes in Climate Forcings and Feedbacks

Research Area: Document and understand changes in climate forcings and feedbacks, thereby reducing uncertainty in climate projections	
Performance Objective: Reduce uncertainty in climate projections through timely information on the forcing and feedbacks contributing to changes in the Earth's climate.	
0-2 Year Milestones	Complete Climate Change Science Program 2.4 Synthesis and Assessment product on stratospheric ozone and ozone depleting gases
3-5 Year Milestones	Climate research on upper tropospheric water vapor to improve models that provide a predictive understanding of the physical processes affecting water-vapor concentration in the mid-to-upper troposphere and lower stratosphere.
	Quantify changes in air-sea CO2 fluxes and carbon transport in the North Atlantic over the last decade

Longer term research includes efforts to better constrain the uncertainties of the feedbacks of water vapor in radiative forcing, better linkages of the effects of increasing atmospheric carbon dioxide on marine ecosystems, and an emphasis on integrating radiative-forcing process research into the next generation of climate models.

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7.4.3 Improve skill of climate predictions and projections and increase range of applicability for management and policy decisions

The focus of this theme is to provide climate forecasts for multiple time-scales to enable regional and national managers to better plan for the impacts of climate variability, and provide climate assessments and projections to support policy decisions with objective and accurate climate change information. Research within this theme provides the nation with a seamless suite of environmental forecasts (i.e. outlooks and projections) on intraseasonal, seasonal, interannual, and multidecadal timescales and on regional, national, and global spatial scales, to understand and predict abrupt climate change, and to promote credible national and international assessments of future climate trends and change. The global environment includes not only the atmosphere, hydrosphere, cryosphere, biosphere, and lithosphere, but also land/ocean biogeochemical processes, ecosystems, atmospheric chemistry, and air quality.

Historically, NOAA's seasonal and intraseasonal (S/I) forecasting capability was based on empirical tools; improvements will result from increased reliance on ensembles of coupled ocean–atmosphere–land models, advanced post-processing methodologies, and improved understanding and modeling of seasonal climate processes. New product suites will be developed for water resource and ecosystem forecasts. Model runs using observed anthropogenic and sea surface temperature forcings and coupled Earth system and regional models will become a new tool for decadal predictions in the near future. Further improved and higher resolution models including interactive carbon, atmospheric chemistry, and biogeochemical cycles.

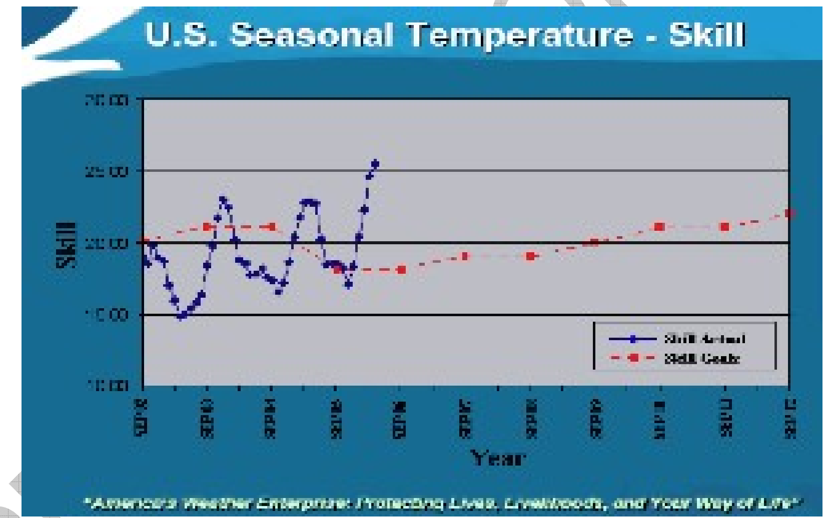

Fig. 7.3. NOAA's Climate Test Bed provides the ability of NOAA research to directly contribute to the skill of the operational seasonal forecasts. Early benefits from prototyping this activity is shown in recent improvements in the skill of U.S. seasonal forecasts.

The long-term goals are sets of decision support tools for resource managers and policy makers based on a seamless suite of forecast and simulation products for intraseasonal, interannual, and multi-decadal time scales that enable more reliable estimates of the impacts of climate variability and change on physical variables, ecosystems, and life resources, especially those related to the water cycle. This will require research to produce increasingly capable Earth system models and linking forecast and simulation products from global to regional to local scales. Research will be coordinated with related work under the Weather and Water Goal to ensure seamless product and application suites at the weather-climate interface (between days 10-60).

Table 7.4. Selected Research Milestones and Performance Objectives for Improving Climate Predictions and Projections

Research Area: Improve skill of climate predictions and projections and increase range of applicability for management and policy decisions	
Performance Objective: Improve climate predictive capability from weeks to decades, with an increased range of applicability for management and policy decisions	
0-2 Year Milestones	Complete CCSP Synthesis and Assessment Product 3.3 on climate extremes
	Complete CCSP Synthesis and Assessment Product 3.2 on climate projections based on emission scenarios from CCTP
3-5 Year Milestones	Develop a capability to make sea level projections on decadal to centennial timescales, Arctic forecasts, and anticipate climate 'surprises' through the development of extramural 'centers of excellence' grants programs

7.4.4 Understand impacts of climate variability and change on marine ecosystems to improve management of marine ecosystems

The focus of NOAA's Climate and Ecosystems research is to develop forecasts of changes in coastal and living marine resources in response to climatic changes. These forecasts provide users and managers the information they require to adapt to changing climate conditions. Changing climate is among the most significant long-term influences on the structure and functioning of marine ecosystems and must therefore be taken into account to ensure healthy and productive ocean environments. NOAA must understand the effects of climate on marine ecosystems in order to meet its responsibilities for the management of living marine and coastal resources. An understanding of how climate impacts living marine resources is also necessary for the implementation of an ecosystem-based approach to management. The Climate and Ecosystems Program is intended to be a national program with projects in regions where there are ecologically and economically significant coastal and marine resources impacted by climate variability and change. This program aims to build a bridge between "physical and chemical forcing" and "ecosystem response" through observations, modeling, and research, leading to a better understanding of the critical factors that link climate variability and ecosystem response.

To accomplish this, the program will focus on the following activities in the next five years:

- Conduct Climate Regimes and Ecosystem Productivity projects in each of the large marine ecosystems around the U.S.
- Continuously monitor changes in coastal and marine ecosystems through an integrated network of in-situ and remote observing systems, especially in the Arctic and sub-Arctic.
- Produce a suite of physical and ecological indicators based on modeling and observations, and make use of climate sensitive "sentinel species and sentinel sites," to help determine the current and future status of the climate and ecological systems for coastal and resource management. Such indicators are analogous to "leading economic indicators" and "stock indices" used extensively by the business community.
- Investigate the effect of elevated CO_2 and associated acidification of the ocean on calcifying organisms such as corals.

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Table 7.5. Selected Research Milestones and Performance Objectives for Understanding Impacts of Climate Variability and Change on Marine Ecosystems

Research Area: Understand impacts of climate variability and change on marine ecosystems to improve management of marine ecosystems	
Performance Objective: Understand and predict the consequences of climate variability and change on marine ecosystems	
0-2 Year Milestones	Development of a model to incorporate the effects of climate into living marine resource assessments for the Bering Sea
3-5 Year Milestones	Initiate a competitive program on Loss of Sea Ice in the Arctic and climate and ecosystem regime shifts in the California Current

Achieving the research milestones will require collaboration with the academic research community, ongoing ecosystem research programs under the Ecosystem Goal, other federal and state agencies, and appropriate international partners. Customers for climate and ecosystems data products and services include coastal communities, municipal planners, coastal resource managers, tourism councils, fisheries stock assessment scientists, Fisheries Management Councils, offshore aquaculture, and individual fishers.

Research over the next five years will provide a foundation for longer-term research. Climate and ecosystem interactions are highly complex, and developing an understanding of the biophysical processes through which ecosystems are affected by climate, sufficient to develop a predictive capability for all resources of interest, will likely take decades.

7.4.5 Enhance NOAA's operational decision support tools to provide climate services for national socio-economic benefits

Research and related activities associated with regional decision support in the NOAA Climate Program provides information and tools to support decision makers in improving management of risks to the U.S. economy in sectors and areas that are sensitive to impacts from weather and climate. This includes annual losses from drought, the negative impacts of strong El Niño and La Niña events, sea level rise, and other high impact climate events.

NOAA's Regional Decision Support program addresses an increased demand for traditional climate services, such as data and forecast dissemination and customer support, as well as identifying and satisfying new requirements for decision support in sectors such as water, fire, emergency preparedness, health, transportation, energy, coastal, urban, and ecosystem management. These research activities build bridges between producers and users of climate information, allowing decision makers to participate in the creation of new knowledge, processes, tools, and products to improve planning, risk management, resource allocation, impacts assessment and mitigation, early warning, and operational response in sectors sensitive to climate variability and change. Demand for increased services is met through research into decision maker needs and prototype product development, transition of research products into application and operations, and operational delivery and support of climate services. This program leverages partners at the international, national, regional, state, and local levels, academia as well as rely heavily on NOAA's extensive infrastructure. Education and training programs contribute to ensuring that NOAA personnel are best able to deliver data, information, products, and services based on sound research that meet the needs of the public and decision makers.

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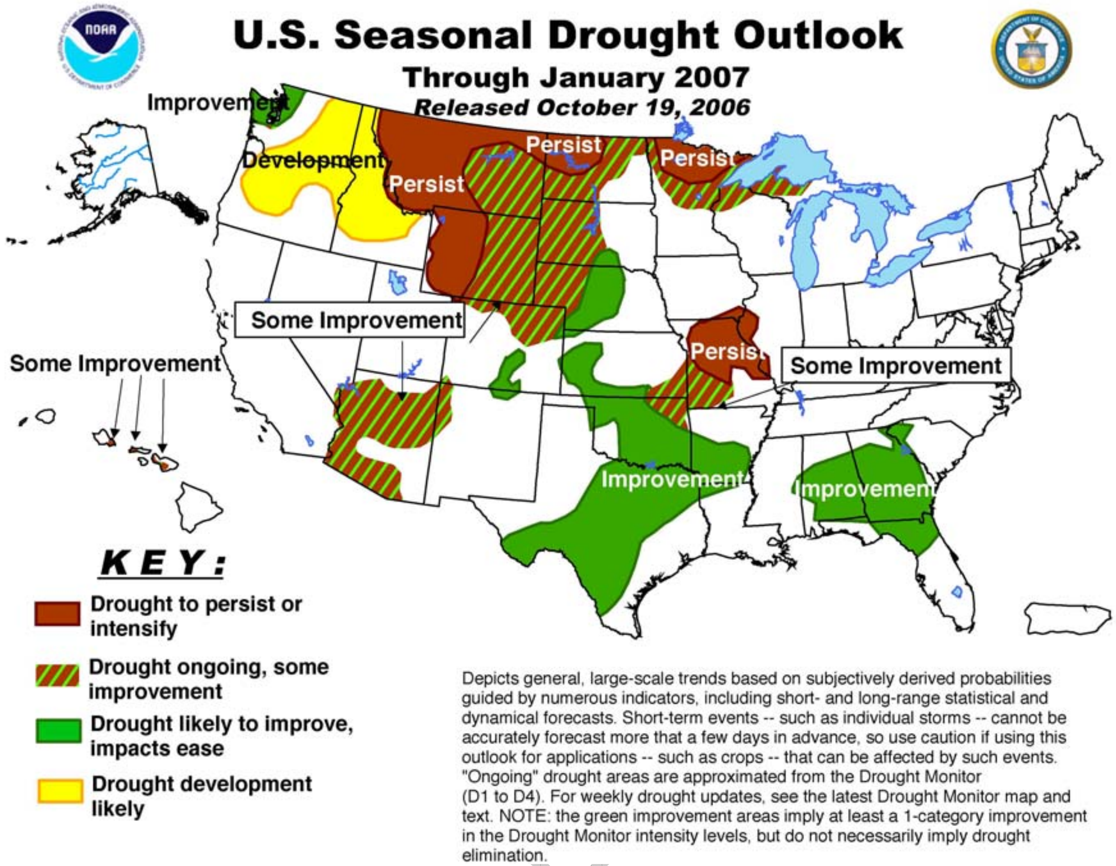

Fig. 7.4. Figure shows the large scale seasonal trends of drought in the United States. This outlook saw abundant rains offering drought improvement from the Southwest into the Lower Mississippi Valley. This product is an example of NOAA's commitment to providing the public with understandable climate information.

Activities under this focus area are to:

- Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change (Strategic Plan of the U.S. Climate Change Science Program. 2003);
- Create a Drought Early Warning System for the 21st Century by establishing the National Integrated Drought Information System (NIDIS) per a request from the Western Governors' Association;
- Coordinate among NOAA line offices the transition from investigator-driven research projects to operational facilities, capabilities, and products.
- Support educational efforts to create a more climate-literate public by developing climate educational materials, involving teachers in the research process, and generating tools to allow climate information to be used in decision-making.

Table 7.6. Selected Research Milestones and Performance Objectives for Enhancing NOAA's Operational Decision Support Tools

Research Area: Enhance NOAA's operational decision support tools to provide climate services for national socio-economic benefits
Performance Objective: Increase number and use of climate products and services to enhance public and private sector decision making

0-2 Year Milestones	Establish a NIDIS Office to integrate drought information including operational services, research and tool development, monitoring, and integrated observing systems.
	Lead the production of CCSP Synthesis and Assessment Product 5.2 on characterizing uncertainty in decision making and S&A 5.3 on evaluation of decision support experiments

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8. Weather and Water Mission Goal: Serve Society's Needs for Weather and Water Information

8.1 Introduction

Each year thousands of lives and billions of dollars are lost due to severe storms, floods, heat waves, and other natural events. Damage from Hurricane Katrina alone exceeded $40 billion insured dollars. Potential hurricane landfall disasters are a growing concern because of population shifts to hurricane prone coastlines. Death and damage from severe convective storms and their attendant phenomena (tornadoes, hurricanes, and flash floods) also continues to have major impacts on the nation with over $11B in damages per year (2006 *Report on Economic Statistics for NOAA*). One of the growing national concerns is simple availability of fresh water. Regions in which water was once plentiful are now experiencing shortages. Our nation's freshwater supply is critically stressed by a growing population and climate change, especially in environmentally sensitive areas along the coasts. The National Research Council has stated: "In this century, the United States will be challenged to provide sufficient quantities of high-quality water to its growing population." The Western Governors Association estimates that economic losses arising from the current drought in the West are billions of dollars." In addition, wildfire costs have averaged over $1B a year, and costs and risks are increasing as building along the edge of wildland forests continues. Poor air quality has had a significant effect on our nation's health and economy as pollution causes an estimated tens of thousands of premature deaths and more than $100 billion in costs per year. Although complete protection from weather and water events is not possible, considerable amelioration in deaths and property losses could be achieved with modest increases in forecast and warning skill.

Continued improvements in the ability of individuals and organizations to plan for and react to weather and water related impacts are critical to advancing community resiliency to natural events throughout the United States. The nation's ability to anticipate and plan for these weather and water related impacts have been enhanced through NOAA's weather, water, and climate forecasts and warnings. One particular example, hurricane track forecast improvements, illustrates the progress NOAA has made in improved forecasts due largely to NOAA research results. Coincident with this increasing trend in forecast skill has been the establishment of a Joint Hurricane Testbed in Miami. Testbeds allow the evaluation of new science and technology in a setting that mimics NWS operations.

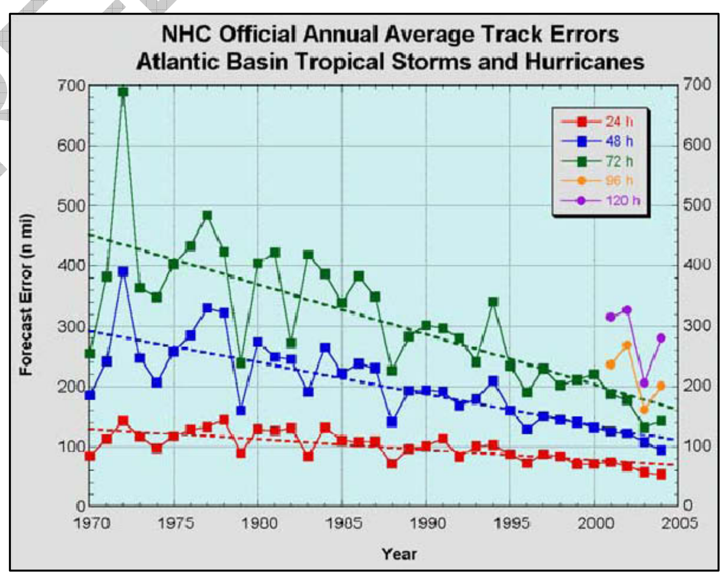

Fig. 8.1. Annual average hurricane track forecast errors from 1970 to 2004. NOAA's Joint Hurricane Test Bed provides a conduit for research results to move rapidly into operations. Benefits from this activity is seen in recent acceleration in skill of 24, 48, and 72 hour hurricane track forecasts. Such reduction in forecast track errors has given confidence in extending the forecasts, since 2001, to longer time ranges (i.e., 96 and 120 hours).

Many other examples of accelerating progress in forecast skill in Weather and Water are evident. For example, in the

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last decade, the lead time for tornado warnings increased from 6 to 13 minutes, due largely to the $4 billion investment in the network of new Doppler weather radars (WSR-88D). This investment has reduced tornado fatalities by 45% and injuries by 40% from their already historically low levels in the late 1980s and early 1990s”. Moreover, the NWS NEXRAD radar system prevented over 330 fatalities and 7800 injuries from tornadoes between 1992 and 2004, at a monetized benefit of over $3 billion. Lastly, four-day hazardous weather outlooks have become as accurate as two-day forecasts were two decades ago.

8.2 Developing and Applying the Research Tools

NOAA research focuses on technological developments in the major components of prediction: observational science, quality control, analysis, and ingestion of the observational data (e.g., data assimilation), improved numerical modeling, and user products and other services. Beyond reducing errors, a new emphasis will be on the description of uncertainty at all stages in the forecast process. Observations drive improved understanding of important processes. NOAA will integrate multi-purpose observing systems, especially those involving radars, satellites, and profilers, and obtain better observations of environmental parameters. The new observations will be digested by advanced data assimilation methods, reducing the error in the ensuing forecasts. Numerical modeling, including ensemble techniques, will focus on reducing and representing all forecast uncertainty for use in existing and new forecasts and warnings. Altogether, these improvements will lead to enhancements in NOAA’s flagship weather and water forecast products to better serve the needs of the user community.

8.3 Outcomes and Performance Objectives

Table 8.1. Weather and Water Goal Outcomes and Performance Objectives from the FY2006 – FY2011 NOAA Strategic Plan

Outcomes	Performance Objectives
Reduced loss of life, injury, and damage to the economy Better, quicker, and more valuable weather and water information to support improved decisions Increased customer satisfaction with weather and water information and services	• Increase lead time and accuracy for weather and water warnings and forecasts. • Improve predictability of the onset, duration, and impact of hazardous and high-impact severe weather and water events. • Increase application and accessibility of weather and water information as the foundation for creating and leveraging public (i.e., Federal, state, local, tribal), private and academic partnerships. • Increase development, application, and transition of advanced science and technology to operations and services. • Increase coordination of weather and water information and services with integration of local, regional, and global observation systems. • Reduce uncertainty associated with weather and water decision tools and assessments. • Enhance environmental literacy and improve understanding, value, and use of weather and water information and services.

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8.4 Research Areas

To meet future service delivery goals to the nation, NOAA must address a number of existing scientific and technological deficiencies. To enhance the utility of end products, and following recommendations from the National Academies, increased emphasis will be placed on the development of tools to account for uncertainties at all stages of the forecast process, from observations, data assimilation, numerical modeling, through user products and services. NOAA is committed to improving the accuracy and capabilities of its monitoring and observing systems both in situ and remotely sensed, including improving the timeliness, data quality, and long-term continuity of observations necessary to reduce observational, analysis, and model initialization errors and provide a basis for improved verification of all forecasts. NOAA is committed to accelerating the development of new environmental observational technology and sensors, including state-of-the art observational uncertainty estimates.

Advanced data assimilation techniques are required to improve the quality of analyses and model initialization, and to maximize the value of existing and new observational data sets, with a focus on the newer more voluminous satellite data sets, including satellite sounding systems from polar orbiting platforms. Critical to the forecast process is the estimation of uncertainty in the initial conditions used in numerical prediction. Ensemble-based data assimilation methods will be further developed, along with techniques to estimate uncertainty in more traditional, variational data assimilation schemes.

Environmental predictive models and information delivery systems must be improved through community model development, including improving and coupling numerical modeling systems to adequately simulate weather, air quality, water, climate, and other geophysical phenomena in common modeling systems. Common operational and research models accelerate the transition of research results (e.g., higher resolution and improved representations of physical processes) into improved products and services. To quantify forecast uncertainty, NOAA will improve probabilistic prediction systems by advancing ensemble modeling techniques and partnering with international modeling centers to determine the optimal combinations of model resolution and number of ensembles to maximize accuracy while providing quantitative measures of forecast certainty (with varying dynamics, physics, and initialization). Representation of model-related errors in ensemble forecasting is an area of particular interest for properly capturing forecast uncertainty in probabilistic products.

In addition, NOAA’s Science Advisory Board (SAB) is chartering a Fire Weather Research Working Group to assess the effectiveness and efficiency of NOAA's individual and collaborative fire weather research efforts toward meeting current and expected future operational challenges. Further, the Office of the Federal Coordinator for Meteorology (OFCM) Joint Action Group on Wildland Fire User Requirements will soon provide advice to the Western Governors’ Association (WGA) and NOAA as to the best focal areas for future fire-related research. The OFCM Report will cite areas where current operational deficiencies exist that may be improved by future focused research. The SAB working group will make use of the OFCM results. Though these efforts are currently in development, their outcomes will influence NOAA’s future activities in fire weather research.

Research activities that support the above outcomes and performance objectives are organized by research areas and are described below along with their associated research milestones.

8.4.1 Improve weather forecast and warning accuracy and amount of lead time

Critical weather information falls short of national demands and expectations due to a variety of factors. These factors include: incomplete understanding of meteorological processes, inadequate

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frequency and coverage of environmental observations, inadequacies in data assimilation and numerical modeling, and a continuing gap between the providers and users of meteorological information. The basic understanding of why tornadoes form, the process of hurricane formation and intensification, and the ability to forecast precipitation amounts sufficient to forecast flash floods are among the weather research challenges ahead. Other research issues that must be addressed include linking larger-scale global circulation fluctuations to specific local severe weather outbreaks, improving data assimilation efforts, establishing a multidisciplinary approach to models that link various fundamental components, and addressing short-range rapid changes in mesoscale environments that affect high-impact phenomena like thunderstorms. NOAA must also increase its knowledge of the space environment and advance the development of prediction models of solar and geomagnetic storms. An understanding of these processes will be critical if forecasts and warnings are to continue to improve.

Scientific and technological advancements of the forecast system, however, do not guarantee enhanced utility of forecast products for society. NOAA will enhance its support for research related to the socio-economic use of weather and water information. This will involve the development, in partnership with our users, of more useful products that convey uncertainty in all environmental information and the assessment of the socio-economic value of forecasts to better integrate meteorological and hydrological services into the nation’s economy.

Research results are now emerging that provides insight into the appropriate amount and type of observational data needed to address these deficiencies. NOAA’s challenge is to determine the most cost-effective means for observing the sun, space, the atmosphere, land, water cycle, and ocean to support these requirements. Once the data are collected into a coherent format, assimilating them into numerical models to describe the current state of the environment for use by forecasters, researchers, and modelers will continue to be a priority of NOAA-funded research.

NOAA will conduct, direct, and leverage research and development in cooperation with other federal agencies and the academic community to better understand the key processes governing the environment. Research will be conducted in NOAA laboratories, academia, and elsewhere to improve predictions of high-impact weather (e.g., fire weather, hurricanes, winter storms, associated heavy precipitation, and floods). This research will add critical information and understanding about weather hazards to improve models. One promising new technology being explored in the Hazardous Weather Testbed is the impact of very rapid radar observations of storms using Phased Array radar technology. Another example involves coupling advanced data assimilation systems with real-time Doppler observations provided by reconnaissance aircraft of the hurricane’s inner core. Such a more realistic initialization of forecast models is expected to bring a dramatic increase in intensity predictive skill of hurricane track and intensity forecasts. Lastly, NOAA will participate in targeted field experiments and observing system studies, and will conduct diagnostic modeling studies to better understand specific forecast challenges.

NOAA will advance data assimilation and the transfer of new research and technology into operations through testbeds. As an example, assimilation of fixed, mobile, and airborne radar systems continue to be tested to improve storm predictions. Polarized radar has shown great potential to improve quantitative precipitation estimation (QPE), and phased array radar technology shows promise in providing higher resolution data both spatially and temporally to help improve lead time in forecasting severe storms. Satellite-derived winds have been shown to be of significant use in marine weather forecast and warning issuance. These data will be used to improve the understanding of extratropical cyclones that reach hurricane force intensity, supporting not only Weather and Water Goal objectives, but Commerce and Transportation Goal needs. The process of incorporating these and other new technologies into operations will be a challenge for NOAA. The use of testbeds will continue to expand and put new technology and

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researchers in an operational framework to evaluate new ideas and techniques to smooth the transition from research to operations.

Lastly, NOAA will improve winter storm observations, tracking, and develop improved precipitation measurements, precipitation type, wind observations, to provide more effective forecasts and warnings. Fire weather research is required to improve upon fire weather guidance and analysis graphics containing weather parameters deemed important for fire weather conditions and forecasting. Specifically, the June 2005 Western Governors Association Policy Resolution #05-04 clearly states the position that "...an integrated fire weather and fire environment research program is critical for the effective management and health of U.S. forests and rangelands. To ensure the program has proper attention and funding, the Governors urge Congress to legislatively direct the National Academy of Sciences to conduct a review of the research programs related to fire weather and fire environment (including Department of Agriculture, Department of the Interior, EPA, NOAA, NASA, and academia). This review should focus primarily on the coordination process between research programs and on processes to transfer research results into fire operations." NOAA will participate in these activities.

The 5-agency (NOAA, NSF, NASA, the Navy, and the Air Force) U.S. Weather Research Program (USWRP) has and will continue to provide opportunities for leveraged research and transition of research to operations directed toward accelerating the improvement of weather forecasts. In recent years, its investments have mainly focused on hurricane forecast improvements, including establishing the Joint Hurricane Testbed. These investments will continue, but opportunities to also focus on improvements in precipitation forecasting will be exploited. Recognizing the importance of understanding the societal and economic aspects of weather and also recognizing that there was no national focal point for such research and assessment, the USWRP initiated the Societal Impacts Program (SIP), at the National Center for Atmospheric Research (NCAR). The SIP is already gathering national attention for its work on economic and social-behavioral information related to weather.

Beyond exploiting collaborative opportunities at the national level, NOAA is also engaged in international research programs to address global weather and water prediction problems. NOAA scientists are actively engaged with the World Meteorological Organization's (WMO) World Weather Research Program (WWRP). In particular, NOAA participates in THe Observing system Research and Predictability Experiment (THORPEX), a 10 year (2005-2014) major research program aimed at accelerating improvements in the utility of weather forecasts, with an emphasis on extending the useful skill of probabilistic predictions out to 14 days. Because extended-range prediction requires a global approach (collecting observations around the globe, and using data assimilation and numerical modeling tools applied over the entire global domain), THORPEX offers a unique opportunity to leverage advances in science and technology at other operational and research organizations across the globe. THORPEX is also partnering with climate experts to bridge the current gap between weather (out to 7-14 days) and climate (beyond 30-60 days) forecasting, with the aim of developing the next generation intra-seasonal (10-60 days) forecast systems.

Table 8.2. Selected Research Milestones and Performance Objectives for Improving Weather Forecasts and Warnings

Research Area: Improve weather forecast and warning accuracy and amount of lead-time	
Performance Objective: Increase lead time and accuracy for weather and water warnings and forecasts	
3-5 Year Milestones	Conduct a risk-reduction program for the phased array radar technology. Gather data sets of severe weather hazards and test algorithms to extend warning lead-time
	Deliver a space environment forecast model that improves forecast accuracy by 25%

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Performance Objective: Increase development, application, and transition of advanced science and technology to operations and services	
0-2 Year Milestones	Using the testbeds, transfer up to 6 research results into operations per year
Performance Objective: Improve predictability of the onset, duration, and impact of hazardous and severe weather and water events	
3-5 Year Milestones	Determine viability of data assimilation approaches (e.g., ENKF, 4-D Var)
Performance Objective: Increase coordination of weather and water information and services with integration of local, regional, and global observation systems	
0-2 Year Milestones	Improve the accuracy of measurements of geomagnetic activities and solar energetic particles by 25%
Performance Objective: Reduce uncertainty associated with weather and water decision tools and assessments	
3-5 Year Milestones	Improve the accuracy of global analyses by 25% through better ensemble and statistical post-processing techniques
	Evaluate the utility of probabilistic forecasts for hazardous weather

8.4.2 Improve water resources forecasting capabilities

NOAA needs to expand its hydrology program and services to meet broader national water resources information needs driven by societal demands for better water management. While NOAA has produced streamflow and flood forecasts for several decades, there is an increasing demand for an expanded suite of water resource predictions to support flood mitigation and manage water availability and quality for agriculture, potable water, hydropower, thermal power cooling, sustainable ecosystems, navigation, and contaminant loading. NOAA will integrate its research and operational assets to deliver water resource predictions and information. Although the accuracy of flow forecasts has improved, there is a need to conduct research and development to address challenging problems, such as increasing the lead time for flood warnings and flow predictions, and quantifying and reducing the uncertainty in these estimates.

There are several research challenges that will be addressed by activities in the FY 2007-2011 time frame. Flow forecasts will include all ranges from droughts to floods, which will require the explicit modeling of entire watersheds. River forecasting models will have to account for the potential releases and evaporation losses from reservoirs in a watershed, the influence of surface water diversions and return flows for irrigation and domestic water supply, and the effect of groundwater pumping on river flows. Research will be conducted to improve our understanding and predictions of the sub-seasonal variability in rainfall and the onset and cessation of heavy rainfall events. For instance, studies indicate economic benefits of up to $200 million annually from improved soil moisture information for private irrigation management in just two states in the Great Plains. NOAA will improve its Advanced Hydrologic Prediction Services (AHPS) to monitor and predict the runoff from snow-melt, forecast snow levels, and monitor soil moisture which can precondition runoff rates. AHPS will be enhanced by improving multi-sensor precipitation algorithms and using digital radar mosaics and dual-polarimetric variables. Because of the substantial economic impacts of reservoir operations on power generation, flood control, and potable water and agricultural water use, these research efforts will include social scientists. Research and development of radar systems (e.g., polarized radar) and technologies (e.g., multi-sensor QPE algorithms) are needed to improve the accuracy of radar measurements of precipitation, both in quantity and type of precipitation. Research and development of microwave remote sensing of snow and ice are needed to improve estimates of drought severity, regional water supplies, soil moisture, and snowmelt flood forecasting. Leveraging satellite instrumentation to observe precipitation, snow water content, and soil moisture and incorporating satellite

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information to fill in gaps in the ground-based radar coverage is necessary to improve hydrologic models. A new generation of high-resolution distributed rainfall-runoff models will be developed. These new models will be coupled with mesoscale weather models to make better use of data to increase the accuracy and specificity of river and streamflow predictions. Research is needed to advance understanding of uncertainty and assimilation of observations into this new generation of distributed models. Research is needed to advance the understanding of the effect of climate phenomena to develop a new generation of long-range hydrologic prediction products for prudent allocation of water resources. This research will require the coupling of ocean, atmospheric, and hydrologic models.

Table 8.3. Selected Research Milestones and Performance Objectives for Water Resources Forecasting

Research Area: Improve water resources forecasting capabilities	
Performance Objective: Increase development, application, and transition of advanced science and technology to operations and services	
0-2 Year Milestones	Deliver improved echo classification techniques that significantly reduce contamination of precipitation estimates using dual-polarization radar technology
	Using a combination of improved radar estimates and satellite data, evaluate the improvement in Day 1 and 2 precipitation forecasts in terms of equitable threat scores
3-5 Year Milestones	Evaluate community-wide rainfall - runoff distributed hydrologic models
Performance Objective: Increase application and accessibility of weather and water information as the foundation for creating and leveraging public (i.e., Federal, state, local, tribal), private and academic partnerships	
3-5 Year Milestones	Evaluate the socio-economic impact of improved water resources forecasts in terms of dollars saved
	Develop an equitable and efficient water allocation model for multi-use reservoirs based on forecasts of climate variability
	Improve the Advanced Hydrologic Prediction Services (AHPS) through improved multi-sensor precipitation estimation algorithms including dual-polarization and digital radar mosaics.

8.4.3 Provide information to air quality decision makers and improve NOAA's national air quality forecast capability

NOAA now provides air quality forecast guidance for the eastern U.S. The initial operational capability, deployed in 2004 over northeast U.S., was expanded in 2005 to provide predicted surface ozone concentrations over a domain three times larger. These are first steps in producing timely and accurate air quality forecasts nationwide to help people limit adverse effects of predicted poor air quality. NOAA provides air quality decision makers with scientific information and tools for making decisions that have large public health and economic consequences. For instance, revisions to Houston's air quality management plan based on NOAA's research findings are estimated to save $10 billion and 64,000 jobs by 2010. Research is required in three key areas: model development, regional models, and improved measurement tools to monitor long-term trends. NOAA is a leader in the development of air quality assessments of tropospheric ozone and particulate matter levels to support air quality forecasting and development of air quality policies and plans. NOAA researchers, along with their partners, are developing new approaches to predict with enough accuracy and lead time not just ozone but particulate matter, an issue that contributes to tens of thousands of premature deaths nationally each year. Future research will improve the accuracy of the air quality predictions to extend the forecast interval to several days and beyond, and enhance the quality and accuracy of information they provide. NOAA, along with partners from academia and other agencies, will also perform regional assessments that identify

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and characterize the key atmospheric processes that control air pollution transport and transformation in areas that have serious air quality problems. A central element of each assessment is a comprehensive regional field study that deploys state-of-the-art instruments to measure myriad weather and air quality parameters from the ground, air, and sea. These assessments provide information that allows regional and urban decision makers to better protect public health while maintaining economic vitality and also provide scientific advancements that can be used to improve models. In addition, NOAA will develop improved measurement tools in support of national operational networks that monitor long-term trends of deposition of atmospheric pollutants to the surface. These trends are used to evaluate models, the effect of air pollution policies, and atmospheric influences on land and water bodies.

Table 8.4. Selected Research Milestones for Providing Information to Air Quality Decision Makers and Establishing and Improving a National Air Quality Forecast Capability

Research Area: Provide information to air quality decision makers and improve NOAA's national air quality forecast capability	
Performance Objective: Improve predictability of the onset, duration, and impact of hazardous and severe weather and water events	
3-5 Year Milestones	Provide a prototype model suitable for implementing new particulates forecasts
	Develop an advanced air quality model by linking the Weather Research and Forecasting (WRF) model to chemical processes for regulatory assessments
Performance Objective: Reduce uncertainty associated with weather and water decision tools and assessments	
0-2 Year Milestones	Conduct field campaign to determine role of nocturnal chemistry on regional air quality
3-5 Year Milestones	Gather regional data sets to assess deposition trends
Performance Objective: Increase development, application, and transition of advanced science and technology to operations and services	
3-5 Year Milestones	Develop 3 new measurement tools that monitor long-term deposition trends

8.4.4 Improve NOAA's understanding and forecast capability in coasts, estuaries, and oceans

The NOAA research community will integrate and improve weather and water information, warnings, and forecasts in our coastal zones to provide services as accurate, comprehensive, and responsive as over our nation's interior areas. There are four distinct research challenges to move to knowledge-based decision-making tools—1) the development of an integrated observation system; 2) the need for an integrated assessment of the forecast system; 3) the development of integrated dissemination and outreach; and 4) accelerated transition of research results to integrated operations.

Scientific research and technology development will expand process models and work toward coupled models for coastal, estuary, and ocean and improve the linkages between fresh and saltwater models and those between biological and physical-chemical models. Research will improve forecast capabilities by enabling integration of wind, wave, water level, ice, storm surge, current, tsunami, and related data. Seamless descriptions and understanding of coastal, estuarine, ocean, Great Lakes, and inland areas will be enhanced by research integrating erosion, flood, riverine, hydrodynamic, wind, ocean circulation, storm surge, and related processes. This will also require data assimilation and improvement in observational capabilities in coastal zones. Research activities will support the network of ocean, coastal, and Great Lakes observing systems

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to improve the accuracy, resolution and coverage in the nation's ports, bays, estuaries and open oceans. New techniques of observing and monitoring coastal regions from existing and new satellite sensors will be developed. Enhanced observational sensors and monitoring techniques will enable expansion and enhancement of a more complete and cost-effective system of national coverage.

A primary outcome will be a suite of tools and associated outreach and training to enhance community resilience to weather and water conditions. The research and development will make weather and water information, forecasts and warnings in coastal zones as comprehensive and responsive as over our nation's interior. NOAA will integrate and improve its environmental information products and services for the nation's coastal zones. A focused research and development program in ocean science will contribute to the development of an expanded and integrated suite of coastal water prediction products. Research is required to identify and characterize the key transition zone processes to predict true coastal flooding and its impacts. In addition, evolving coastal and ocean, coastal, and Great Lakes observations will be incorporated into new ocean system prediction algorithms and models to achieve new forecasts.

Table 8.5. Selected Research Milestones for Improving Understanding and Forecast Capability in Coasts, Estuaries, and Oceans

Research Area: Improve NOAA's understanding and forecast capability in coasts, estuaries, and oceans	
Performance Objective: Improve predictability of the onset, duration, and impact of hazardous and severe weather and water events	
0-2 Year Milestones	Demonstrate a transition zone modeling system to integrate river, estuarine, and coastal models
3-5 Year Milestones	Develop and evaluate an improved resolution (1/4 degree) global ocean model for predicting currents and ocean status, including Tsunami

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9. Commerce and Transportation Mission Goal: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

9.1 Introduction

NOAA provides information, products, and services fundamental to:

- the safe and efficient movement of people, goods and services,
- the nation's competitive position in the global market,
- and reducing risk to the environment from transportation and cargo related accidents.

NOAA provides critical information that moves America and, equally important, contributed to the increase in efficiency that our transportation and logistics systems have seen over the last two decades. U.S. maritime trade is expected to double by 2020, impacting the overburdened Marine Transportation System (MTS) infrastructure even further. Two-thirds of all goods purchased in the U.S. come to us via the MTS. Contributing roughly $1 trillion annually to the U.S. economy, the MTS employs 13 million people and ships over 95% of the tonnage and more than 37% by value of our foreign trade through America's ports. In addition, the U.S. coastal recreation and tourism industry, with over 17 million recreational boats, has an annual economic value of about $24 billion to the country.

"NOAA's information products and services are essential to the safe and efficient transport of goods and people on the sea, in the air, on land and through inland waterways. More accurate and timely warnings of severe weather events, effective marine navigation products and services and improved positioning data can better support the growing commerce on our roads, rails, and waterways."

-- VADM Conrad Lautenbacher, Jr. to the Senate Committee on Commerce, Science, and Transportation's Subcommittee on Oceans, Fisheries, and Coast Guard

The nation's air transportation system forecasts as much as a threefold increase in demand for air capacity by 2025, necessitating research foundations in the next 5 years to mitigate weather impact on aviation. The movement of goods and people on our roadways also is headed for gridlock, with accidents related to weather on the rise as more cars and trucks take to the roads. Hazardous weather conditions are associated with over 1.5 million vehicular accidents, which result in 800,000 injuries and 7,000 deaths annually. Delays in arrivals of people and goods (trucking, rail, transit, pipeline, ferry, and airport ground transportation factors) result in more than $42 billion per year in economic cost. These growth and demand forecasts are intermodal and interrelated as our economy is dependent upon the land, air, and sea transport modes to move forward.

Recent events such as the 2005 hurricanes have also highlighted the fragility of our transportation systems; our reliance on them for goods, services, and movement, spills and debris impacts; and their reliance on NOAA for accurate and updated information about current environmental conditions to make decisions. These high impact events demonstrate the need for advance

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planning and preparedness to respond effectively, save lives, protect property and the environment, and help impacted communities and industries get back to business.

From the Organic Act of 1807, which created the Survey of the Coast, through today's Homeland Security Presidential Directive, NOAA and its predecessor organizations have worked in partnership with other Federal, state and local agencies, academia, and the private sector to develop, maintain, and improve a safe, efficient U.S. transportation system. Several mandates from the U.S. Congress, the Executive Branch and international treaties provide the requirements for the Commerce and Transportation (C&T) mission goal. The mandates span the breadth of the mission goal and require NOAA to: enhance national economic performance through an efficient U.S. transportation system; reduce risks to life, health, and property through development and use of the U.S. transportation system; protect the security of the U.S. transportation system; and ensure environmentally sound development and use of the U.S. transportation.

To fulfill this mission, it is necessary to acquire a wide array of data, ranging from periodic to continuous, ocean to land and the atmosphere, and utilizing both fixed and mobile platforms, both in situ and satellite. Real-time observations, analyses, and forecasts of temperature, wind, pressure, precipitation, and visibility are provided to support the nation's diverse land-based economy. Real-time and forecast navigational data are acquired, and products (such as nautical charts) are distributed to mariners navigating our waters and key players active in port and harbor development, from the ice-covered waters in Alaska to the small estuaries along our coasts. Corresponding observations and forecasts, involving a mix of automation and human value-added features, facilitate safety, efficiency, and optimal capacity of surface and air transportation.

Appropriate research and development is needed to maximize the quality and efficiency with which NOAA acquires, manages, and distributes its data and associated products and services to ensure they are accurate, reliable, secure, understandable, timely, appropriate, and readily accessible to meet the stringent demands of the transportation sector.

Research under this mission goal will support and improve NOAA's ability to accurately and rapidly disseminate up-to-date nautical charts, critical chart corrections, and specialized mapping products. Accurate and rapid dissemination of weather observation and forecast information is also critical to air and surface transportation systems. Research will also lead to an increase in the number of coastal communities with the capacity to respond to spills and other hazards that result from manmade or natural disasters by offering forecasts of oceanic and atmospheric dispersion of hazardous materials, and giving emergency responders reliable tools to take action and geographically position resources.

9.2 Developing and Applying the Research Tools

Accurate and timely observations are integral to the safe and efficient movement of people, goods, and services in our nation. Research supporting the Commerce and Transportation Goal objectives includes enhancing existing instrumentation, investigating and validating new sensors, and transitioning the results to operations. Requirements are established, standards and protocols are followed, thorough testing including comparison to benchmarks is accomplished, and scientific peer review is performed. Modeling techniques are used to analyze and couple ocean and atmospheric dynamic geophysical processes leading to improved marine and weather forecasts; a consistent and accurate positioning capability; and enhanced preparedness, response, and restoration abilities from natural or manmade disasters. Integration of the appropriate observations, integrated assessment capabilities, and model output with improved

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decision-making tools will allow the user community to better meet the rising demands of the growing transportation system.

9.3 Outcomes and Performance Objectives

Table 9.1. Commerce and Transportation Goal Outcomes and Performance Objectives from the FY2006 – FY2011 NOAA Strategic Plan

Outcomes	Performance Objectives
Safe, secure, efficient, and seamless movement of goods and people in the U.S. transportation system Environmentally sound development and use of the U.S. transportation system	• Enhance navigational safety and efficiency by improving information products and services. • Realize national economic, safety, and environmental benefits of improved, accurate positioning capabilities. • Reduce weather-related transportation crashes and delays. • Reduce human risk, environmental and economic consequences as a result of natural or human-induced emergencies. • Increase total government procurements from NOAA-licensed commercial firms operating remote sensing systems.

9.4 Research Areas

The research activities that support the outcomes above are organized by areas described below along with their associated research milestones.

9.4.1 Explore, develop, and transition emerging technologies and techniques to enhance marine navigational safety and efficiency

NOAA's data are presently required to support safe and efficient navigation while transiting our nation's waters. For example, NOAA data are used to update NOAA's nautical charts and to define our nation's shoreline and maritime boundaries. New and improved sensors and sensor systems will improve the safety and efficiency of navigational services provided by NOAA, which translate into cost savings for shipping operations and reduced risks due to groundings, accidents, or collisions. These data are also used to support many non-navigational needs such as characterizing sensitive marine habitat, building storm surge and tsunami models, monitoring subsidence, surveying hurricane evacuation routes, supporting homeland security initiatives, and determining the effects of hazardous storms. Customers include the navigation community (pilots, captains, and recreational boaters), coastal managers, emergency managers, meteorologists, and climatologists, and there is a continuous dialogue with users to determine needs and requirements.

Continued research, development, and systems integration is required for remote sensing technologies—such as multibeam, side scan sonar, topographic and bathymetric Light Detection and Ranging (LIDAR), imaging spectroscopy, and Synthetic Aperture Radar (SAR)—that are used to acquire, process, and manage survey data; NOAA is gaining efficiencies from these versatile instruments and continuing to extract new products from them. NOAA tests and evaluates oceanographic and marine meteorological sensors and systems to improve the quality, responsiveness, and value of individual sensors or integrated sensor systems to customer requirements. Performance testing, quality assurance, repeatability, and endurance assessments

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are provided to a level required by NOAA to accept legal liability required for navigational products and services. Partnering with other government or private organizations that specialize in new sensor testing and/or development is a key component in this overall effort. NOAA works closely with the Joint Hydrographic Center (JHC) at the University of New Hampshire. JHC is a national center for expertise in ocean mapping and hydrographic science. Its research focuses on developing and evaluating a wide range of state-of-the-art hydrographic and ocean mapping technologies and applications.

Also required is development of Autonomous Underwater Vehicles' (AUVs) and Unmanned Aerial Systems (UASs) regarding applications, efficiency, ability to meet standards, and integration into survey operations. In support of both hydrographic surveying and coastal mapping efforts, these vehicles could be significant "force multipliers" by increasing data acquisition and decreasing costs as well as increasing the overall safety of these operations. NOAA needs to build its capability and capacity in this arena, test and validate these systems, define the operating procedures and standards, and develop a strategy to transition the systems to an operational status.

In FY 2006, NOAA, NASA, and a private sector firm successfully evaluated the potential for Unmanned Aerial Systems (UAS) to meet NOAA operational needs. The Altair UAS was used to carry a variety of sensors including the Digital Camera System (DCS) and Electro-Optical Infrared (EO/IR) Sensor to demonstrate how operational needs of NOAA could be met in future UAS flights. The DCS was used in shoreline mapping and in along-shore/inland feature characterization for habitat mapping/ ecosystem monitoring. The EO/IR system was used for fisheries surveillance and marine mammal surveys.

Continued development is required to investigate new products and services including delivery mechanisms such as GIS and web-based interactive programs. Among the GIS techniques to be developed are algorithms that take advantage of newly acquired, complete coverage bathymetric data to optimize potential claims for an extended continental shelf under United Nations Convention on the Law Of the Sea (UNCLOS) Article 76. Also, continued effort is needed in the technology of data visualization, particularly in the development of new and unconstrained paradigms in electronic navigational charting. Successfully developed technology and software whose use would result in increased efficiency, cost savings, and/or accuracy will be transitioned to operational use. Close cooperation with the private sector is essential throughout the entire process to facilitate the incorporation of standard-compliant techniques into industry products.

Table 9.2. Selected Research Milestones and Performance Objectives for Emerging Technologies and Techniques

Research Area: Explore, develop, and transition emerging technologies and techniques to enhance marine navigational safety and efficiency	
Performance Objective: Enhance navigational safety and efficiency by improving information products and services.	
0-2 Year Milestones	AUVs with side scan sonar transitioned to integrated operations
	Enhanced method of determining and applying tide correctors for hydrographic surveying transitioned to operations
	Evaluation microwave sensor technology for suitability as primary water level sensor
	Bathymetric database of NOS hydrographic survey point data populated

	Evaluation of use of bi-static and multi-static high frequency RADAR measurement systems
3-5 Year Milestones	Evaluation of use of high frequency RADAR for wave height determination
	UAS R&D technology and integration into survey operations investigated
	Emerging airborne technologies, such as LIDAR and Digital Imaging Systems enhanced
	Performance testing, quality assurance, repeatability, and endurance assessments of marine meteorological sensors and systems as applicable
	New concepts and technology for processing, analysis, and management of hydrographic and ocean mapping data

9.4.2 Provide accurate, timely, and integrated weather information to meet air and surface transportation needs

To mitigate the adverse impacts of localized weather conditions, travelers and transportation operators need weather advisories based on timely, fine-resolution weather observations along the nation's roadways and airways to enable them to make the most informed transportation decisions. Local effects such as fog, blowing and drifting snow, ice, high winds, thunderstorms, and other hazardous weather conditions can impact travel conditions with very short notice. NOAA will engage international, federal, state, and local agencies; academia; and private industry partners to join NOAA, the Federal Aviation Administration (FAA), and the Federal Highway Administration in defining and validating the roles and requirements necessary to provide accurate and timely information to meet air and surface transportation needs.

Research and development needs for real-time weather data collection apply to all surface transportation modes but will address highways as a priority and for prototype purposes. The near-term focus is as follows:

- Standardizing methods of data gathering, archiving and exchange;
- Assessing the refinements needed to meet surface transportation needs (performance standards, densification, accuracy, siting criteria, proprietary data);
- Developing an integrated prototype observing methodology at selected transportation choke points or high impact areas; and
- Demonstrating integration of mesonet data, surface transportation data, and the modernization of the NOAA Cooperative Observer Network, based on weather sensor-equipped vehicles positioned with GPS or other advanced technology.

An aircraft-based water vapor sensor was successfully field tested in 2005-2006 on commercial aircraft. Results of the test were presented at the American Meteorological Society Conference in 2006. Increased observations from sensors deployed using aircraft of opportunity will support improvements to numerical models used in NOAA products and services.

Looking to the future, research will concentrate on sensor development to adequately determine surface conditions, technology for data sharing and transmission, and incorporating human factor engineering into products/services including usability, education, and training.

In December of 2006, the President signed Executive Order 13419, "National Aeronautics Research and Development" which directs the Department of Commerce (DOC) to join other

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executive departments and agencies to “develop a national aeronautics R&D plan.” This Executive Order also gives DOC the responsibility to conduct foundational research that “advances the sensing and prediction of atmospheric and space processes that contribute to global weather impacts on the aeronautics enterprise.” Air transportation research has traditionally been primarily the purview of the FAA, which funds research and development of new aviation weather products through on-going programs in academia, the private sector, and NOAA labs. NOAA implements the emerging products and creates innovative ways of incorporating them into the forecast process, thus highly leveraging FAA research dollars in carrying out the NOAA mission. Implementation of this Executive Order may enhance NOAA’s responsibility for performing this research.

In addition to high-resolution weather observations, high-resolution weather forecast information is also essential. Current weather infrastructure and models support good regional weather forecasts for many public safety purposes; however, further modeling efforts are required to bridge the gap in resolution and precision between ideal surface and air transportation needs (1-2 km) and the existing model resolution (12 km). High-resolution regional and local observations must be assimilated into present modeling efforts. Also, existing models need to be enhanced by adding forecasts of additional surface and air parameters, such as surface and ground heat and moisture exchanges; icing (ground and aloft) and atmospheric turbulence; and by adding tools for decision assistance including risk/uncertainty information.

Research and development will also focus on creating a NOAA nowcast/forecast database that can be used by the private sector to improve products and to facilitate use by “intelligent” decision-support systems. Constituent expertise and partnerships will be sought and developed to ensure the information will meet the needs of the transportation sector. A prototype will be developed for disseminating transportation safety weather information, including both model guidance and real-time data, with the option for users to customize the locality of information displayed based on the actual position of the vehicle determined with GPS or other advanced technology. In the aviation sector, the Next Generation Air Transportation System’s (NextGen) Joint Planning and Development Office had developed a comprehensive 4 Dimensional (4D) database concept that will provide a single authoritative source of weather observation and forecast information to ensure consistent input to decision-making systems and to promote common situational awareness among all components of the air transportation system. Considerable research will need to be conducted to determine the best way to populate this continuously updated database, and how best to integrate meteorologists into the 4D forecast process.

As research and development regarding roadway and air transportation matures and transitions into operations, integration of scientific capabilities and activities towards intramodal (e.g., rail and transit) and intermodal (e.g., aviation and marine) transportation forecasting should commence. For example, NOAA will seek out synergies and efficiencies between road weather research and parallel efforts regarding other modes of transportation, such as the database discussed in the preceding paragraph. Coupling of weather with oceanographic forecasts will occur. Continued research and development of oceanographic forecast models are required for transition into an operational environment for more efficient transit scheduling, oil spill response, and other applications. Forecast capability enhancements are discussed in the Weather and Water Goal, section 7.3.4.

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Table 9.3. Selected Research Milestones and Performance Objectives for Integrated Weather Information

Research Area: Provide accurate, timely, and integrated weather information to meet air and surface transportation needs	
Performance Objective: Reduce weather-related transportation crashes and delays.	
0-2 Year Milestones	Standards and protocols for weather-related electronic data exchange
	Validated methodologies for acquisition, processing, and dissemination of weather-related data
3-5 Year Milestones	Research weather-observation prototypes transitioned into full operational use
	Private sector partners enabled to market acquired tools and expertise
	Aviation database concept with weather elements prototyped

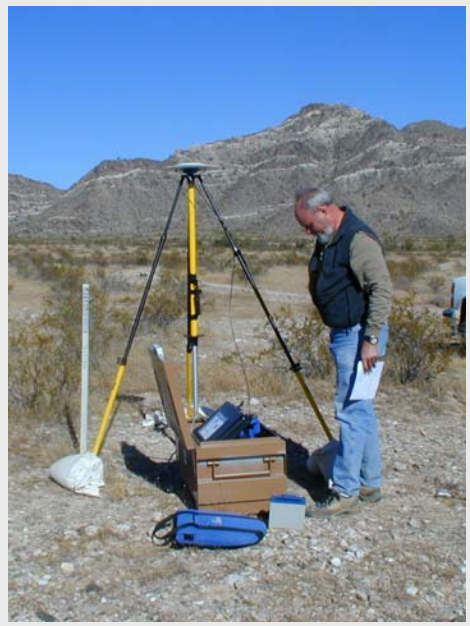
9.4.3 Improve accuracy of positioning capabilities to realize national economic, safety, and environmental benefits

Geodesy is the science of measuring and monitoring the size and shape of Earth and its gravity field and is used to understand physical processes on, above, and within the Earth. Scientists can determine exactly how much Earth's surface has changed over time by obtaining highly accurate horizontal and vertical positions. In addition, using the Global Positioning System (GPS), the public now has the ability to determine their location within meters on or above the surface of the Earth. (With additional augmentations and/or observing times, accuracies of 1 cm are achievable). This capability to accurately position an object or person has proven to be essential for the transportation industry to support the safety of people, goods, and services, while reducing costs.

NOAA's National Spatial Reference System (NSRS) is a consistent national coordinate system that specifies latitude, longitude, height (dynamic, orthometric, and ellipsoidal), shoreline, gravity, deflections of the vertical, scale, and orientation throughout the nation, as well as how these values change with time.

NSRS consists of the following components:

- A consistent, accurate, and up-to-date National Shoreline;
- the CORS, a set of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations meeting NOAA geodetic standards for installation, operation, and data distribution;
- a network of permanently marked points including the Federal Base Network (FBN), the Cooperative Base Network (CBN), and the User Densification Network(UDN);



Since 2002, NOAA has made available to the public OPUS, the Online Positioning User Service. This tool, the culmination of years of GPS research and CORS infrastructure building, allows anyone with a single geodetic-quality GPS receiver to position themselves in the National Spatial Reference System to an accuracy of 2 centimeters with just 2 hours of data. Further research is ongoing to reduce the amount of field time to just minutes. The number of users has grown from about 1,000 per month in FY 2002 to over 13,000 per month in FY 2005.

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- A set of accurate models describing dynamic geophysical processes affecting spatial measurements;
- A model of surface gravity, geoid undulations and deflections of the vertical;
- A full set of access tools, such as Online Positioning User Service (OPUS), GEOIDxx software, Surface Gravity Prediction software, Datasheets, etc

Research activities, carried out within NOAA in collaboration with academic and commercial entities, are performed to support NOAA's mission to provide the nation with the National Spatial Reference System (NSRS), which enables a consistent, accurate, and timely positioning capability nationwide. The tools developed reside onsite but are made available to the public via the Internet when appropriate. The program also has recently initiated a new federal-funding opportunity. Research and development planned in the NSRS arena includes:

- Quantification of gravimetric geoid accuracy improvements due to the addition of coastal airborne gravity data.
- Development and improvement of GNSS data processing techniques which allow for cm-level positioning in 15 minutes rather than the current 2 hours required by OPUS.
- Mathematical proof that 1 cm accuracy geoid is achievable, quantification of required data sources to achieve such accuracy, and a description of which areas of the United States can not practicably achieve such accuracy and why.
- A complete investigation of modern geodetic leveling instruments and data reduction methods for updating NGS standards, specifications and guidelines on leveling.
- Empirical quantification of positioning improvements due to the addition of either GLONASS or L2C data to existing GPS data collection and processing.
- Geographically dependent accuracy assessment of the gravimetric geoid through Monte Carlo methods and independent slope-checks from a combination of GPS and leveling.

NOAA is also developing a vertical datum (VDatum) transformation tool. Although people can now position themselves accurately on Earth using GPS, their vertical position is referenced to a mathematical surface (an ellipsoid) used to simplistically represent Earth. This ellipsoid, with knowledge of its position relative to the center of mass of Earth, represents one type of "datum". A datum is a reference level to which geospatial data are positioned. For example, in the interest of navigational safety, NOAA collects water depth data relative to Mean Lower Low Water, and shoreline data relative to Mean High Water. The U.S. Geological Survey presently has its land elevation data referenced to NAVD 88 (and other datums.) Geospatial data collected by NOAA and many other agencies and entities, particularly data collected in coastal regions, suffer from being tied to many different vertical reference datums. Therefore, the vertical datum (VDatum) transformation tool is being developed to address this problem.

VDatum translates geospatial data between 28 different vertical reference systems and removes the most serious impediments to data sharing allowing for the easy transformation of elevation data from one vertical datum to another; geospatial data can be seamlessly integrated. VDatum also allows NOAA to make full use of recent technological advancements [such as integration of depth data from an aircraft using a laser (LIDAR)] that will greatly improve the efficiency with which it acquires new and more accurate data for NOAA's nautical, navigational, and geospatial products and services. VDatum will also improve the efficiency and accuracy of hydrographic surveys for nautical charts by eliminating the need for time-consuming water level corrections and post processing.

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With the completion of VDatum in our nation's waters and advancements in the "awareness" of electronic navigation chart (ENC), electronic charting systems and Electronic Chart Display and Information Systems (ECDIS) will be possible. A vessel's exact position in the water can be accurately determined using Differential GPS. This information could then be incorporated into the charting system along with real-time display of actual water depths for the entire body of water. This will allow danger areas to be identified, displayed, and adjusted depending on a vessel's draft as it transits through areas of concern.

VDatum development involves multiple efforts from gathering tidal information, geodetic ties, and tidal and geoid modeling. Work is progressing along our nation's coastlines to build the supporting database and tool.

Table 9.4. Selected Research Milestones and Performance Objectives for Positioning Capabilities

Research Area: Improve accuracy of positioning capabilities to realize national economic, safety, and environmental benefits	
Performance Objective: Realize national economic, safety, and environmental benefits of improved, accurate positioning capabilities.	
0-2 Year Milestones	15 minute GPS data collection time for OPUS (reduced from 2 hours)
	Comprehensive accuracy analysis of current gravimetric geoid model
	Modernization of standards, specifications, and guidelines for geodetic leveling
	Methodology to attain 1-cm geoid model accuracy
	Recognized standards and procedures for VDatum
3-5 Year Milestones	Methods to transition between regional areas in VDatum for a seamless database
	Near-real-time positioning system integrating real-time CORS with real-time ionosphere and troposphere models for single frequency GNSS users
	New orbital computation software capable of yielding sub-cm accuracy GNSS orbits

9.4.4 Develop the information and tools to make reliable decisions in preparedness, response, damage assessment, and restoration

Building on capabilities developed in the recent past, a fluorescein dye solution, mixed to a density and concentration to simulate a dispersed oil plume, was deployed during the 2006 Safe Seas exercise. The horizontal and vertical micro-scale movements of water were successfully measured, supplying needed data that will improve 3-D modeling capabilities and will refine the protocol for monitoring dispersed oil.

Thousands of incidents occur each year in which oil or chemicals are released into the coastal environment. Spills into our coastal waters, whether accidental or intentional, can harm people and the environment and cause substantial disruption of waterways with potential widespread economic impacts. In the US alone, 3,000,000 gallons are typically spilled into the water each year. Most of these spills are the result of human error, aging infrastructure, and/or bad weather. In 2005, Hurricanes Katrina and Rita contributed to an estimated 8,000,000 gallons of oil released into the coastal environment. The nation's dependence on the marine transportation system creates an ongoing need to efficiently develop preparedness and response actions that reduce the risks of spills and minimize the impact on commerce,

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communities, and the environment when spills do occur.

NOAA is working to develop a comprehensive strategy to identify and readily access the information necessary for reliable decision-making in preparedness, response, damage assessment, and restoration activities. NOAA's research for spill response and restoration science is implemented through the Coastal Response Research Center (CRRC), a partnership between NOAA and the University of New Hampshire . A core component of the CRRC mission is to apply research results to improve our basic understanding of coastal and marine spills and, most importantly, advances our capacity for:

- Responding to spills in a manner that minimizes the impacts to biological, economic, social, and cultural resources.
- Assessing the impacts of both the spill and the response efforts on those resources.
- Restoring the impacted resources with the highest degree of efficiency and effectiveness.

The use of alternative response technologies (e.g., *in-situ* burning or the use of dispersants) remains an area of active research. There are two recent examples of how the use of alternative response technologies has been applied to improve response capabilities and reduce impacts to resources.

1) *In-situ* burning was applied to an oiled marsh that resulted from Hurricanes Katrina and Rita. The burn resulted in removal of 80-90% of the oil from the marsh, enabling a faster recovery of the marsh environment. Post-burn monitoring studies have documented recovery, and have provided a baseline for further research in understanding long-term recovery. This effort directly affected other sites, and set a precedent for using ISB for other Katrina/Rita-related spills.
2) CRRC and the State of California leveraged resources to fund researchers to develop improved methods for modeling, monitoring, and assessing damage associated with dispersing oil. This effort has measured horizontal and vertical diffusion using synoptic remote-sensing, fluorometry, and GPS-integrated drifters and drogues using fluorescent dye mixed to simulate chemical dispersion as the tracer of horizontal and vertical micro-scale water movement. This study will directly improve NOAA's 3-D modeling capabilities and will refine the protocol for monitoring dispersed oil.

NOAA also is advancing its assessment capabilities by developing a robust database for managing shoreline assessment information for large and complex spills. Assessment of marine debris is also integrated into the database structure and field tools development. Part of the development includes improved use of GPS integrated into digitally collecting field data through the use of a handheld device. This system will allow NOAA and its partners to eliminate the bottle-neck that occurs when field teams report back to the command post with hand-written field notes. This system also improves NOAA's ability to manage data and affect decision-making using GIS and improves the speed and efficacy of sharing data layers.

Currently, 50% of the CRRC-funded projects examine the issues of measuring and predicting the effects of oil and dispersed oil components on ecological endpoints. Improved understanding in this area and an improved ability to predict ecological consequences will improve the speed and efficiency and effectiveness of response and restoration. NOAA is working directly with researchers to ensure results are translated to the field-relevant level.

In addition, NOAA has identified the societal, economic, and cultural consequences of spills and associated response activities on affected communities as a high priority for research. Specific

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project topics have been identified as a result of a recent workshop where a diverse group of social and natural scientists, responders, impacted parties, and potential responsible parties worked together to delineate research needs for improved understanding and effective response to: subsistence, social impacts, response organization impacts, risk communications, and environmental ethics issues. This area of research has the potential to greatly affect commerce and transportation by revolutionizing the response organization.

With the growing usage of heavier crude oils and refined products, the percentage of non-buoyant oil spills has increased over the last decade. Nonfloating oils provide response challenges significantly different than for floating oils. Technology for tracking and predicting the behavior of submerged oil remains in its infancy. Currently, there does not exist robust and effective ways to remotely detect sunken oils under realistic field conditions nor sufficiently understand its ultimate fate. The lack of detection, monitoring, and modeling capabilities hampers effective protection, containment, and recovery of submerged oil. NOAA is working with the USCG and CRRC to develop an integrated and effective research strategy to improve modeling, detection, and monitoring capabilities for submerged oil.

This information is used not only by NOAA, but also by external customers such as the U.S. Coast Guard; U.S. Army Corps of Engineers; Minerals Management Service; U.S. Navy; Environmental Protection Agency; individual state governments; energy development, production, and transportation firms; spill response and clean up firms; marine transportation firms; and port authorities. NOAA works closely with these entities on a daily basis to ensure research and activities are relevant.

Table 9.5. Selected Research Milestones and Performance Objectives for Decision-Making Information and Tools

Research Area: Develop the information and tools to make reliable decisions in preparedness, response, damage assessment, and restoration	
Performance Objective: Reduce human risk, environmental, and economic consequences resulting from natural or human induced emergencies.	
0-2 Year Milestones	Field tools transitioned to operations that improve the efficiency of oil spill and marine debris assessment
	Refined methods for modeling and monitoring dispersed oil/chemical plumes based on current research.
3-5 Year Milestones	Synthesized results of funded research projects on chemical impacts of oil spills and field-relevant products
	Research results implemented from understanding the human dimensions (social, cultural, and economic) impacts of spills and response activities
	Research strategy for submerged oils to improve preparedness, detection, modeling, and recovery

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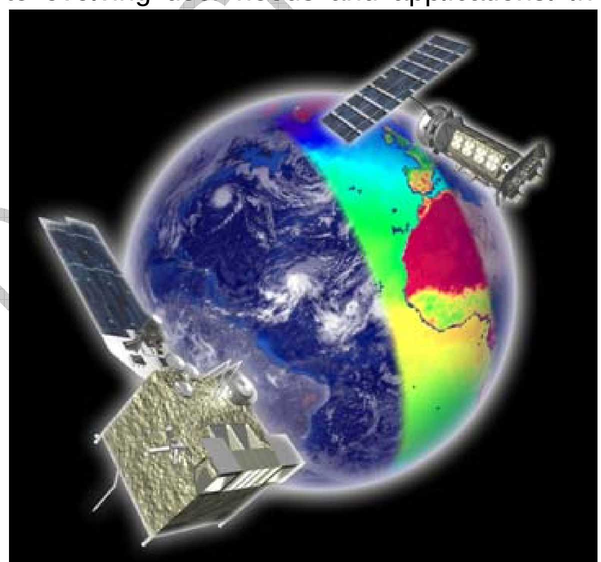
10. Technology and the Mission Support Goal: Provide Critical Support for NOAA’s Mission

10.1 Introduction

NOAA’s observing systems are a critical part of its infrastructure under the Mission Support goal that supports the outcomes in all four of the Mission Goals previously mentioned. These observing systems measure more than 500 environmental parameters via platforms that include geostationary operational environmental satellites (GOES), polar-orbiting operational environmental satellites (POES), ground-based weather and climate monitoring systems, ocean and coastal buoys, submersibles, ships, and aircraft. Continuous research is required to improve the information products obtained with these systems, to design new products, and to develop the technology for observing systems of the future. Mission Support research links the design, acquisition, and application of observing platforms to evolving user needs and applications. In addition, this research explores integration opportunities across observing systems and data sets to provide better products for the operational community (for example, new forecast models using both satellite and ground-based GPS data) and for researchers (for example, long-time series data sets for climate change research).


The NOAA GOES (left) and POES (right) satellites are integral to monitoring key weather and climate variables.

New technology opens the doors to groundbreaking discoveries and new knowledge that enable the transition from research to new applications. Sensors on operational observing systems provide a diverse and large quantity of data used in research studies. Research also greatly benefits from technologies that support the processing and ready access of raw data. In addition, operational observing and data management systems are developed as integral parts of research projects themselves.

NOAA’s satellite observing systems provide a significant portion of the Earth observation data used by NOAA as well as users around the globe, including NOAA’s international partners, commercial users, defense agencies, and the academic research community. Working with the operational community, NOAA conducts ongoing research to increase the accuracy and utility of satellite products and provides on-orbit calibration and validation for operational and experimental satellites used in generating operational products, validating new scientific applied solutions, and ensuring satellite derived algorithms/products meet system specified requirements. These ongoing research and development and operational calibration/validation efforts contribute directly to improved forecasts through improved model initialization and comparison of analyzed satellite data with other information in National Weather Service Forecast Offices. NOAA is also evaluating the recommendations of the National Research Council’s “Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond” to further improve its interactions with partners in satellite research.

Vessel fleet modernization and sustainable operations are critical to support both existing and emerging technologies for data collection such as autonomous underwater vehicles (AUV),

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remotely operated vehicles (ROV), and new sonar technologies. Requirements to meet international data collection standards, such as underwater radiated noise established by the International Council for Exploration of the Seas (ICES), necessitate employing the latest design criteria for hull shape, propellers, equipment mounts, deck machinery and navigational positioning as seen in the new Fishery Survey Vessel (FSV) class. The next generation multi-mission vessel class, NOAA Survey Vessel (NSV), is already analyzing program requirements to support continual development in sensor packages. The combination of the FSV and NSV class ships will maximize efficiency and effectiveness of valuable data collection time.

To meet expanding demand for new types of Earth measurements, and for greater data accuracy and coverage (both spatial and temporal), NOAA is planning to deploy major new observing systems such as National Polar-orbiting Operational Environmental Satellite System (NPOESS), GOES-R, and an enhanced Climate Reference Network. Acquisition of these systems requires research to develop the sensors and products needed to meet system and user requirements.

10.2 Outcomes and Performance Objectives

Table 10.1. Mission Support Goal Level Outcomes and Performance Objectives from the FY2006-2011 NOAA Strategic Plan

Outcomes	Performance Objectives
Ship, aircraft, and satellite programs that ensure continuous observation of critical environmental conditions	• Increase quantity, quality and accuracy of satellite data that are processed and distributed within targeted time. • Increase number of ship operating days and aircraft flight hours that meet NOAA's data collection requirements with higher customer satisfaction. • Increase internal and external availability, reliability, security, and use of NOAA information technology and services.

10.3 Research Areas

10.3.1 Advancing space-based data collection capabilities and associated platforms and systems

In the next decade there will be a wealth of new global Earth observations available operationally with GOES-R (geostationary satellite), NPOESS (polar satellites), and METOP (European polar *met*eorological *op*erational satellites). The new generation of operational environmental satellites to be flown by NOAA will have sensors that are much advanced over current operational models. Significant resolution improvements are going to be seen spectrally, temporally, and spatially (see Table 10.2). In addition there are a variety of experimental satellites recently or about to be launched to provide new measurements including Cloudsat (launched in partnership with NASA in 2006 and provides radar capabilities to discern cloud structure and depth), COSMIC (launched in 2006 as a joint project with Taiwan that provides radio occultation measurements to obtain temperature, moisture and electron density profiles with high vertical resolution), the Atmospheric Dynamics Mission (to be launched in 2007 in a joint effort with the European Space Agency to provide wind profiling information with high vertical resolution from lidar technology) and several satellites with polarimetric sensors providing new soil moisture and ocean salinity capabilities.

In addition to the above-mentioned missions, NOAA is investigating new technologies to improve satellite capabilities, such as working towards a "polar stationary" capability via the use of a solar

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sail spacecraft orbiting the Sun at the same rate as Earth. Also being researched is the feasibility of using a “Molniya” orbit, an egg-shaped highly elliptical orbit that “hovers” over the northern latitudes for 8 hours at a time. Other topics of investigation include: Earth-observing satellites along with new instruments such as a geostationary microwave remote sensor that would provide precipitation estimates, diurnal changes of land surface temperature, and moisture features in the presence of clouds; advanced scatterometers for improved detection of ocean surface winds in areas of heavy precipitation; and advanced lidar wind profilers capable of enhanced accuracy and coverage

Table 10.2. GOES-R and NPOESS will provide operational sensor data with significantly more capabilities than the current GOES and POES series

	POES AVHRR/3	**NPOESS VIIRS**
# of channels	5	22
Spatial resolution (best)	1.1 km	750 m
	POES HIRS	**NPOESS CrIS**
# of channels (Longwave Infrared)	20	1305
	GOES Imager	**GOES-R Imager**
# of channels	5	16
Spatial resolution	1 km (vis) 4 km (IR)	0.5 km (vis) 2 km (IR)

AVHRR – Advanced Very High Resolution Radiometer; **VIIRS** – Visible Infrared Imager/Radiometer Suite; **HIRS** – High Resolution Infrared Radiation Sounder; **CrIS** – Cross Track Infrared Sounder.

The NPOESS is the next generation of operational polar orbiting environmental satellites. This program will provide observations with a resolution on the order of 750 meters from a constellation of satellites in polar orbit. In the next 5 years, this NOAA satellite program will verify and validate the observation system and the products delivered by the NPOESS prime contractor. This will entail an operational calibration and validation system be implemented in NESDIS. The NPOESS Environmental Data Records (EDRs) and direct observations taken by this new system will be used in numerous NOAA applications which will yield improved weather predictions, benefiting all the impacted industries. To prepare for the use of the latest high quality observations, the NPOESS data exploitation project will develop and deliver NOAA unique products for NOAA’s operational users.

The GOES-R, the next generation geostationary operational environmental satellite, will provide rapid sequences of imagery and temperature profile information to support forecasts primarily over the United States and the western hemisphere. In the next few years, this NOAA satellite program will provide the initial algorithms to the chosen prime contractor for all of the products requested in the GOES Requirements Document. After selection of the GOES-R prime contractor, NOAA scientists will participate, collaborate with, and guide the prime contractor on algorithm implementation and testing.

The objective of satellite product research and development is to make the NOAA operational satellite data more valuable to our user community. Meeting this objective requires a range of activities from instrument calibration to research into new and novel uses of satellite data. The most basic developmental and applied activity is instrument calibration. Its importance can hardly

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be exaggerated, because an uncalibrated or poorly calibrated instrument delivers a data stream that is much degraded in its usefulness. Users of NOAA satellite data rarely have the expertise to perform calibration on their own, so the calibration is performed within NOAA for all users of the data. By delivering calibrated satellite data from NOAA, quality products and services can be generated by NOAA for users and value-added industries can immediately use the data upon receipt for their own specialized capabilities. By performing the calibration once in NOAA prior to the distribution of the data and products, uniformly consistent information is delivered ‘ready-for-use’ in applications world-wide. This calibration capability also *reduces costs to the entire user community* by eliminating the need for additional quality control, except in specialized circumstances.

The NOAA satellite research and development program develops new and improved algorithms that convert the calibrated satellite data streams into products for use in weather forecast models and by weather, oceanographic, and environmental forecasters. The satellite research effort has high payoffs and results in more accurate forecasts and warnings that generate a large return on investment from the environmental satellites. Many important uses of the current operational instruments were completely unforeseen when the instruments were designed and first launched. Example products included in this category are direct assimilation of atmospheric sounder radiances in weather forecast models, many of the operational imager products (aerosol optical depths, vegetation products of all kinds, radiation budget and quantitative cloud properties), and satellite feature-tracking winds capability – all of which help improve the quality of NOAA forecasts and products. Sensors on the next generation of NOAA satellites, NPOESS and GOES-R, as well as non-NOAA satellites, will have more spectral bands, higher spatial resolution and more frequent image sequences, all of which will require advances in instrument and product calibration/validation. Developing new capabilities to meet both NOAA and user requirements requires NOAA to partner with universities and others to support our satellite product research and development needs.

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NOAA environmental satellites are used to monitor oceanic and atmospheric properties such as ozone, ocean color, coral bleaching, and clouds.

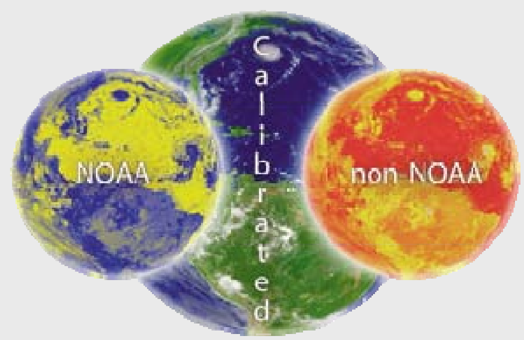
Environmental satellites have both near real-time and climate applications. The satellite data records are archived and have become an important part of the climate record. As more is learned about the environment from new research, the archived data are reprocessed using this new knowledge into updated Climate Data Records for the benefit of users interested in climate trends. These reprocessed products are the climate equivalent of the operational real-time satellite products and forecasts.

NOAA satellite products and techniques are provided to NOAA Offices, NOAA data centers, the private sector, the research community, foreign users, the public, and the media. Consequently, the satellite products span a wide variety of applications and uses. For example, ozone profiles, drought indices, ocean color products, coral bleaching indices, cloud properties, and aviation hazards have all found important uses in the government, the private sector, the public and the international community.

Another objective of NOAA satellite program research is improved instruments and observation techniques for better monitoring of environmental change via future generations of operational satellites. Instrument characteristics such as the spectral sampling, spatial resolution, observation frequency, and geographic coverage must all be selected and demonstrated for new satellites and instruments. Based on satellite research, recommended sensor specifications and characteristics are provided to the NOAA satellite acquisition programs for planning the next generation of sensors and the measurements to be made.

Another important aspect of satellite research and development is the use of satellite data in the numerical models that generate forecasts for local cities, regions, and broad areas in both the atmosphere and the ocean. In this regard, NOAA interacts closely with NASA, DOD, and academia to accelerate and enhance the use of satellite observations in atmosphere, ocean, and coupled atmosphere-ocean models. The Joint Center for Satellite Data Assimilation provides a conduit in which research and operational satellite observations are systematically evaluated and quickly transitioned into the operational forecast models, thereby accelerating the return on investment for the constellation of earth observing satellites. Satellite data have made a large impact on the accuracy of the weather forecast – 5-day forecasts today are as accurate as 3-day forecasts 20 years ago. This significant improvement is largely due to better use of satellite data in NOAA's forecast models.

To ensure the interoperability of a globalized earth observation system, satellites must be carefully intercalibrated.



An increasingly important area in the use of satellite data is leveraging observations taken by our international partners. In support of the Global Earth Observation System of Systems (GEOSS) approach, it is important that all nations contribute their observations to the global community to ensure that the most complete analysis of global, regional, and local environmental changes can be detected, monitored and predicted. For GEOSS to function effectively, it requires: 1) an understanding of the international sensors and how they work, 2) that the international sensors be calibrated and intercalibrated with the other satellite and in-situ observations, and 3) that the data be available in near real time for use in weather and ocean predictions. This expanded international role in satellite research and development is essential for increasing the societal benefits derived from satellite data, and will provide increasing societal benefit as we improve our understanding of how the Earth responds to various stresses and changes. With the recent concurrence of the scientific community that global warming is confirmed[4], the application of global satellite data will monitor the impacts of global warming and will improve global, regional and local prediction capabilities.

Satellite observations are the most efficient and cost effective method for observing and monitoring changes on a planetary scale as NOAA takes the "pulse of the planet." NOAA's satellite research and development program is designed to improve our understanding of environmental dynamics and climate. The ultimate goal of this research and development is to

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[4] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

increase the ability of the nation and the world to make better decisions about our environment, and provide a future in which everyone can enjoy the benefits of planet Earth.

10.3.2 Advancing *in situ* and surface-based data collection capabilities and associated platforms and systems

On-going research is necessary to improve the performance of existing *in situ* and surface-based observing systems and to develop robust, integrated, observing systems of the future. There are ever-increasing demands for observing systems to produce accurate, timely, and spatially and temporally dense data. Advances in sensors and platform development are needed to conduct widespread monitoring of climate and biological signals in near real-time. They are necessary for improving diagnostic and predictive Earth system models on global and regional scales. They are critical for our continued leadership and support of international environmental assessments.

Areas within NOAA that could benefit from the use of Unmanned Aircraft Systems

- Climate and weather operations
- Oceanic and atmospheric research
- Monitoring and evaluating ecosystems
- Monitoring endangered species
- Mapping and charting
- Weather and climate satellite calibration and verification
- Monitoring fires
- Monitoring marine sanctuaries
- Fisheries enforcement

New and improved sensors are needed to enhance the new observation platforms that are being developed. Sensors will be smaller and consume less power. They will be capable of sustained observations and low maintenance and operate in remote and harsh environments. Expanding sensor development for physical, chemical, and biological variables will be pursued. A new suite of diverse and robust sensors will employ state-of-the-art acoustical, microwave, and optical techniques to provide new capabilities for monitoring, mapping, and modeling. These new sensors will be capable of sampling from a wide range of ecosystem types and environmental conditions. NOAA will need to develop sensors and systems that will rapidly detect marine contaminants, pollutants, and harmful non-indigenous species. The new systems will be able to provide measurements of fishery and marine mammal abundance, movements, and habitat use needed to better understand the impacts of environmental change and human activities on the sustainability of managed living marine resources. NOAA will collect information on sentinel organisms and habitats and real-time information on marine, surface, and aviation transportation environments. New technology is needed for long term simultaneous monitoring of climate signals at various spatial scales in real-time. Existing technology will be modified for data transmission from bottom-moored instruments via satellite or for retrieval of data by Autonomous Underwater Vehicles (AUV) or other research platforms.

NOAA plans to conduct research and develop technologies to improve observing systems, including both platforms and sensors. *In situ* observing system platforms are both fixed and mobile and take measurements in space, in the atmosphere and ocean, on the seafloor, on the ground, and across the interfaces between land, air, and water. NOAA is investing research into new approaches, including Unmanned Aircraft Systems (UAS) and Autonomous Underwater Vehicles, and Multi-Function Phased Array Radar (MPAR), to meet increasing demands for observations.

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Unmanned Aircraft Systems (UAS)

UAS's are an example of one emerging technology NOAA is exploring. UAS's have the potential to provide more comprehensive information on atmospheric, oceanic, and terrestrial conditions related to weather, climate, ecosystems, and transportation. Along with the existing fleet of aircraft operated by NOAA and its partners, these unmanned aircraft will expand NOAA's capability from platforms that operate between satellites and sensors deployed on Earth's surface. Measurements from these mobile, unmanned platforms have the potential capability to fill data gaps, link observations to models, and achieve an analytical understanding of global and regional Earth systems. UAS technology is necessary to sample environments that are either impossible or impractical to observe routinely by manned aircraft. The complementary data that UAS's provide could enable us to improve our weather and climate predictions substantially. In addition, UAS may have the potential to conduct extended surveys of marine mammals in offshore waters and enhance our surveillance and protection of marine sanctuaries.

Over the past few years, NOAA has considered how to incorporate UAS technology into scientific and operational missions. In July 2005, NOAA convened an internal UAS Steering Committee and Working Group. This body is responsible for advising NOAA's line offices, goal teams, and programs on the potential application of UAS technology to meet mission goals. The Working Group has also identified common interests and coordinated collaborative activities with NASA, the Federal Aviation Administration (FAA), DOE, NSF, the Department of Homeland Security, the U.S. Coast Guard, and academic institutions. Since 2005, NOAA has worked with its partners to complete several successful UAS demonstration projects. These flights made use of a number of sensors that were designed and developed by NOAA research scientists specifically for these missions. The potential application of these and other sensors to UAS offers a greatly expanded opportunity to understand Earth and regional systems.

In September 2005, NOAA, NASA and industry partners successfully flew an Aerosonde UAS into Tropical Storm Ophelia, the first time a UAS had flown into a tropical storm. This experiment demonstrated the ability of UAS to obtain continuous low-level observations in a hostile environment and may lead to a greater understanding of hurricane intensity.

Other Airborne Systems

NOAA's highly modified airborne platforms support many research efforts through programs like Hurricane Research, Ozone Research, Atmospheric Rivers and Ocean Winds projects. Sensor technologies in these and other disciplines have yielded the development of such instrumentation as the Imaging Wind and Rain Airborne Profiler (IWRAP). This sensor is carried aboard NOAA's WP-3D Orion aircraft and is helping to foster a better understanding of the upper ocean and lower atmosphere by using microwave remote sensing technology to measure profiles of 3-D vector winds and precipitation in tropical storm and hurricane boundary layers.

The NOAA/Hurricane Research Division's Stepped Frequency Microwave Radiometer (SFMR), also carried aboard the WP-3D, is the prototype for a new generation of airborne remote sensing instruments designed for operational surface wind estimation in hurricanes. This instrument was used extensively in the 2004 and 2005 hurricane seasons. In 2005 it proved especially crucial for landfall intensity estimates for hurricanes Dennis, Katrina, Rita, and Wilma.

NOAA's Gulfstream G-IV Jet will carry the Tail Doppler Radar which is planned for integration in FY07 and operation in FY08 in support of the Central Dense Overcast (CDO) mapping mission. The CDO mission is in addition to the G-IV's primary hurricane surveillance mission and involves

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the collection and assimilation of three-dimensional core wind fields with the goal of improving hurricane track and intensity forecasts.

Ground-Based Platforms and Sensors

Ground-based measurements are critical to support virtually all of NOAA's programs and goals. Satellites cannot measure accurately all of the variables needed to understand and predict the Earth system, and virtually all satellite sensors require ground-based measurements to provide calibration, validation, and time trends to account for drift. Aircraft cannot provide the continuity of ground-based networks and are best used in conjunction with ground-based measurements. Many of NOAA's ground-based platforms support weather and climate efforts, but many also are critical to ecosystems and transportation. Improvements in ground-based platforms and sensors are an on-going effort at NOAA, involve efforts of both NOAA scientists and our partners in academic and private sectors, and have allowed us to achieve unparalleled accuracy and precision in many of our measurements. The high quality measurements provided by NOAA's evolving, operational Climate Reference Network are an example of these efforts, as are our global measurements of climatically important gases and aerosols. The value of Multi-Function Phased Array Radar can only be improved by conducting applied research and testing of phased array radar technology and improving airport tracking of aircraft and weather information for civilian use. Improvements in these and other ground-based platforms and sensors allow us to increase the number and frequency of measurements and to reduce the cost of obtaining them. Design of platform distribution is also critical to achieving NOAA's goals and providing effective and efficient information, products, and services for the nation and world. We plan to continue these efforts and maintain and improve NOAA's high quality networks of ground-based observations in the future with the goal of better information and services for society.

Ocean and Water-Based Observations

Supporting NOAA's mission goals is the largest fleet of research and survey ships operated by a federal agency. NOAA's vessel fleet supports a wide range of marine activities, including fisheries and coastal research, ecosystems observation, nautical charting, and long-range ocean and climate studies. NOAA's planned Fisheries Survey Vessels (FSV) are among the most advanced research vessels in the world, including exacting quietness standards to avoid influencing the survey results by disturbing the fish and mammals being studied. The FSVs are purpose-built with multi-mission capability, state-of-the-art technology, long mission endurance, and calibrated to maintain the integrity of long time series of fish and mammal abundance data with which to judge the success of management programs. Multi-mission capability and state-of-the-art technology enables efficient full use of each day at sea and near simultaneous collection of diverse stock assessment and ecosystem data. New design criteria for the NOAA Survey Vessel (NSV) class are looking 20 years into the future to identify emerging mission requirements for at-sea data collection. Research and management of the demanding marine and coastal environment requires specialized platforms and capabilities including not only ships, but also oceanographic buoys, remotely operated and autonomous underwater vehicles, submersibles, sea floor observatories, underwater laboratories, advanced diving techniques, satellites, and manned and unmanned aircraft, as well as the sensors and

> *In 2005 the Office of Ocean Exploration and NOAA's National Undersea Research Program using the human occupied vehicles PICES IV and V, worked together on parts of a 5 month long international expedition to explore the South Pacific. Payoff: The expedition revealed new ecosystems and relationships between ecosystems, new species and new ranges for existing species, measuring marine diversity and finding overlap between chemosynthetic and photosynthetic communities on an undersea volcano.*

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systems that collect marine data. A broad array of platforms, tools, and technologies is essential for supporting research in the oceans. Evolving technologies will continue to improve existing capabilities; developing the tools and techniques to increase the pace and efficiency of marine assessment and prediction. Advanced technologies will be integrated into the NSVs as well as other critical platforms. They will include improvements as well as new applications of advanced acoustic, optical, chemical, physical, and biological sensors and telepresence tools to relay data in real time. This broad range of new capabilities will improve our ability to assess the status of living marine resources and allow the collection of environmental data needed to move from single species management and advance towards the ecosystem approach to management.

10.3.3 Overall observing systems architecture design

The current NOAA Observing Systems Architecture (NOSA) was established to provide an organized management paradigm to optimize the benefits from NOAA's current investments in operational and research observing systems, and identify the research needed to enable increased performance to fill the data gaps. The NOSA activities include three aspects: 1) identifying data collection and analysis requirements, 2) capturing current observing system capabilities to include data management infrastructure, 3) and identifying means to fill those gaps between the most critical requirements and current capabilities.

Observing requirements have been collected in terms of parameters that NOAA's programs need to perform their missions. Requirements to support research are included, to the extent they are known, in addition to operational observing needs. By comparing observing system requirements against the capabilities of NOAA's approximately 85 observing systems, goal teams can gain an understanding of needs. They can use this information as a guide to planning the optimal mix of future investments, and deciding whether and which observations should be taken by space based platforms, airborne, or *in-situ* platforms.

10.3.4 Data management, associated visualization technology & models, and related high performance computing and communication

NOAA's R&D Computing Position

Prior to 2007, NOAA's R&D computing was provided by several vendors at different locations. Each system was "independently owned and operated" by the several NOAA Labs and Centers for the benefit of the users at that site. Under this paradigm NOAA was unable to take advantages of the economies of scale that a single unified research and development system would bring. By combining budgets and requirements, NOAA will be able to increase the value of its overall computing dollar At its completion, this system will provide a significant increase in capacity and capability over the current system, as much as a factor of 6 at one site.

This system, while providing for different hardware, will provide for a common scheduler at the various sites, single user authentication, and an integrated management. NOAA will be able to load manage a significant number of users across the various sites, with minimal impact on code portability. Also, data stored at one site will be available for access by programs running at another site. NOAA is also working toward a portal-access at all of its locations to HPC assets. A single R&D High Performance Computing System for documentation and user support will enhance support to NOAA's entire R&D computing user community.

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Communication and Visualization Technology

Telepresence

In July/August 2005, NOAA's Office of Ocean Exploration sponsored and coordinated with partners a breakthrough, precedent-setting event in "telepresence" capability. This event sent data sets, including images from the mid-Atlantic ocean sea floor, through satellite and high-speed Internet pathways in near-real time to teams of scientists ashore. In addition, for the first time the mission's Chief Scientist was directing efforts from land. All of these experts were thousands of miles from the research vessel and the underwater robots at sea. This was the first time the Chief Scientist and the main group of the science team operated from specially designed Science Command Centers ashore during a major ocean expedition. With scientists ashore at universities around the country, significantly more intellectual capital was applied to this mission than was previously possible. Past missions have been limited by ship-to-shore communications capacity, the limited number of berthing spaces on research vessels, and by competing obligations which sometimes precluded top scientists from going to sea. Scientists received streams of data from the ship's multibeam sonar and, overnight, turned that data into 3D maps of the ocean floor to help scientists and robot operators at sea plan the next day's dives. These high-speed data links connecting scientists ashore with a mission at sea via high-speed Internet2 broke new ground in data distribution and use. In addition, "The Lost City" mission set new standards for sending in near-real time over standard Internet continuous unproduced and frequent produced programs with images and sound from the sea. These programs were provided as educational presentations about the ocean to those ashore in museums, aquariums, Boys and Girls Clubs, and indeed, to any group or individual worldwide with access to standard Internet.

In a pre-cursor mission, NOAA worked with partners to test telepresence technology during a 2003 NOAA-supported expedition to the Black Sea. The same technology was used during the breakthrough expedition to the undersea chimneys of "The Lost City", a mission chronicled at: **http://oceanexplorer.noaa.gov/explorations/05lostcity/welcome.html**.

Telepresence also helps meet key science, education, and outreach objectives associated with the Aquarius Habitat, the NOAA-owned facility that is the world's only undersea laboratory.

Science On a Sphere™

Science On a Sphere™ is a unique visualization technology that allows the projection of global data sets onto the outside of a six foot diameter sphere. Currently, roughly 100 visualization data sets showing images of land, atmospheric, ocean, space, and model simulations are being shown on the sphere. This allows the general public and specifically students to view animations of global events and to visualize complex scientific processes in an understandable way.

NOAA's mission includes observing, understanding, and predicting the future of Earth's oceans and atmosphere. To accomplish its mission, NOAA must help the citizens of the United States understand the global environment, how it affects us, how it is changing, and how the living resources of the oceans are coupled to our current and future well-being. Science On a Sphere™ provides a way to educate citizens about the global oceans and atmosphere. The placement of Science On a Sphere™ into museums and science centers throughout the United States (currently in eleven locations) and potentially other countries provides that education tool.

Data sets of particular relevance to current issues are simulations of potential global warming scenarios over the next 100 years, the movement and development of hurricanes in near real time, modeling phenomena such as tsunamis, and the projection of future observational networks

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such as Unmanned Aerial Systems and DART buoy installations. Science On a Sphere™ is and will continue to be instrumental as a window through which the general public and students in particular will view NOAA research as it evolves over the next several years.

Data Management

A broader system-wide view of data collection, analysis, and preservation will be of increasing importance to help NOAA achieve its research objectives. Data management, in the present context, is the process of consolidating, archiving, and making available the measurements that describe aspects of the Earth's environment. All of the planning, implementation, and operation of Earth observation systems will be of little value if solid data management practices are not in place. Therefore, NOAA will continue to advance comprehensive data management programs that include designated archives for the data and a means for programs to communicate the data to the designated archive in a timely manner. Adding to these endeavors, the international Group on Earth Observations (GEO) is promoting a worldwide view of Earth observation data, leveraging the entire world's resources for the collection, dissemination, and analysis of data germane to nine societal benefit areas. These benefit areas encompass NOAA's mission and contain many similarities to the US/IEOS societal benefit areas discussed in section 3.1.

NOAA is moving forward to design and implement the Global Earth Observation-Integrated Data Environment (GEO-IDE). As a system of systems, GEO-IDE will deploy a Service Oriented Architecture (SOA) by promulgating interoperability standards for use by all observational data systems throughout NOAA. Without replacing existing systems, GEO-IDE will achieve a logical integration, making access to environmental data as easy as using the Internet. Because GEO-IDE is part of an international collaboration, NOAA researchers will achieve simplified access to important worldwide data resources.

In addition to the SOA of GEO-IDE, NOAA is moving toward greater integration of the hardware and software systems now being used. A large number of stove-piped systems exist today. As the NOAA Enterprise Architecture is developed and implemented, the number of disparate systems will decline, and a higher level of commonality will exist among remaining systems.

The Comprehensive Large Array-data Stewardship System (CLASS) system, NOAA's enterprise data and information archival solution, provides a common IT infrastructure for multiple archival datasets, including GOES, POES, and Defense Meteorological Satellite Program (DMSP) data. A major effort is now underway to leverage this success by providing a common IT solution for smaller, but much more numerous, datasets.

With GEO-IDE and CLASS, climate and ecosystem researchers will eventually be able to do one stop shopping, electronically accessing highly diverse datasets through a single portal. Ease of use modifications, including high-performance interfaces and geospatial search, will enhance the productivity of NOAA's researchers.

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11. Managing Our Research

NOAA strives to balance its near-term responsibility to address immediate information needs with a long-term commitment to visionary research. This visionary research will create the next generation of decision-support information products and environmental services. A balanced portfolio of near- and long-term research and high risk-high payoff projects will yield the greatest benefits to the nation, enable credible science to inform policy debates around today's most pressing issues, and provide tomorrow's solutions.

NOAA's research activities are planned at the mission goal level. Scientists from all of NOAA's Line Offices work together to coordinate common requirements, leverage assets, and establish research and development management practices to maximize success. A close working relationship between NOAA's research and operational elements enables research to be responsive to operational needs and keeps operational units informed about the latest scientific developments and possible service enhancements.

11.1 Oversight of Research and Key Research Advisory and Review Bodies

NOAA is committed to maintaining the excellence that has made it a world leader in environmental research and management. NOAA's research activities are subject to peer review for scientific merit and to thorough management oversight to ensure mission relevance.

NOAA employs a senior management official and three oversight boards to integrate and review the agency's research and development activities. These bodies ensure NOAA's research enterprise maximizes its relevance to NOAA's mission goals.

The Assistant Secretary of Commerce for Oceans and Atmosphere and Deputy Administrator of NOAA is the senior management official with the responsibility for overseeing NOAA's research programs. The Deputy Administrator adjudicates issues across NOAA's research program elements and recommends to the NOAA Administrator the creation and implementation of policies and plans for transferring research to operations and information services.

The NOAA Executive Council is the highest level executive management body within NOAA. The purpose of the NOAA Executive Council is to advise the NOAA Administrator before final decisions on NOAA wide policies, including research policies, are made. It is the forum through which NOAA senior management provides advice and counsel on high level operation and management issues. The NOAA Executive Council also provides active oversight of NOAA's research.

The NOAA Research Council is an internal body composed of senior scientific personnel from the Office for Oceanic and Atmospheric Research (OAR), the National Environmental Satellite Data and Information Service (NESDIS), the National Marine Fisheries Service (NMFS), the National Ocean Service (NOS), the National Weather Service (NWS), NOAA Marine and Aviation Operations (NMAO), the Office of Program Planning and Integration (PPI), and NOAA's mission goals. The Council provides corporate oversight to ensure NOAA's research activities are of the highest quality, meet long-range societal needs, take advantage of emerging scientific and technological opportunities, and shape a forward-looking research agenda. The Council is chaired by the Assistant Administrator for OAR and provides support to the NOAA Executive Council and the Deputy Administrator.

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The NOAA Science Advisory Board is an external 15-member Federal Advisory Committee composed of eminent scientists, engineers, resource managers, and educators who advise NOAA on long- and short-range strategies for research, education, and the application of science to resource management and environmental assessment and prediction. The advisory board assists NOAA in maintaining a current understanding of scientific issues critical to the agency's mission. Members are appointed by the NOAA Administrator to serve a three-year term, with the possibility of renewing once.

NOAA also uses several external review bodies, such as the National Academies of Science, the Center for Independent Experts, and others to conduct periodic reviews of its science programs as needed. These reviews are coordinated within the context of the NOAA Science Advisory Board.

NOAA ensures the quality, objectivity, utility, and integrity of research information according to guidelines issued as a result of Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554). NOAA acknowledges that the quality of the information it produces is an important management objective critical to fulfilling its mission. NOAA's research information and products comply with the guidelines issued by the Office of Management and Budget, the Department of Commerce, and NOAA (http://www.noaanews.noaa.gov/stories/iq.htm).

11.2 Planning, Programming, Budgeting, and Execution

This Research Plan unifies NOAA's research enterprise by using a Planning, Programming, Budgeting, and Execution System (PPBES) to enable all research activities, to facilitate integration of all research assets, and to ensure the effective transition of research to application. NOAA's research activities need to support the mission goals described in the NOAA Strategic Plan, and this cross-cutting approach to managing NOAA's research enterprise ensures the greatest value for the American public.

NOAA's research activities fit within the larger goal of accomplishing NOAA's mission. PPBES is a formal, systematic structure for making decisions on policies, strategies, capability development, and resource allocation. PPBES provides the framework to develop a strategic vision for NOAA (Planning), a five-year investment strategy that determines the best way to move NOAA toward that strategic vision (Programming), a budget to accomplish its mission (Budgeting), and an assessment of the conduct of research and progress in meeting goals and objectives (Execution). PPBES allows management to look across NOAA and prioritize activities and resources in areas where there is the greatest global and national benefit.

PPBES incorporates and builds on other governmental management processes. Evaluation of progress towards a goal is good management practice and is required under the Government Performance and Results Act (GPRA). PPBES uses a number of management tools to support informed decision making, including:

- Requirements based management - all activities must support a known requirement such as a legal mandate, a policy, constituent requests, or the scientific advances needed to support progress toward achieving a requirement.
- Performance based management - measuring performance allows managers to evaluate progress and make decisions on the reallocation of existing resources and requests for additional resources, or pursuing other research avenues to achieve desired results. Performance measurement within NOAA is consistent with both the Office of Management and Budget Program Assessment Rating Tool (PART) and the GPRA.

- Capability Gap Analysis – consideration of research and development activities that are not supported under current funding levels is an important tool used to assess priorities for new funding opportunities. Though NOAA's activities must be executed within budgetary boundaries, examination of potential capabilities is a beneficial exercise in evaluating further priorities for NOAA.
- Alternative Analysis - there are often multiple possible ways to achieve a desired result. Careful examination of the ways a goal can be achieved helps to ensure NOAA optimizes its investments.

Active participation by the research community in PPBES ensures a robust research program that contributes to achieving NOAA's goals. There are a number of groups that participate in PPBES that can benefit from input by the research community. These groups include:

- Program Management Teams. Each NOAA program has an officially designated Program Manager. Each Program Manager uses a team of experts on different aspects of the program to assist in assessing program requirements, objectives, and performance. Participation by the research community at the program level is important to ensure research efforts are consistent with and support program requirements and objectives.
- Goal Teams. Each Goal Team has an officially designated Goal Team Lead. Goal Team Leads are responsible for the development of plans that integrate program capabilities to best achieve NOAA's mission goals. Participation by the research community at the Goal level is important to ensure research efforts support NOAA's strategic goals.
- Councils. The NOAA Research Council (described in section 11.1) has the opportunity to assess program plans developed by the Goal Teams. The Council provides its recommendations to NOAA leadership on these plans and can propose alternative courses of action that, while meeting the needs of a Goal Team, also strengthen the overall NOAA research effort.
- Line Offices. Line Offices are responsible for executing NOAA's budget. The research community's participation in Line Office processes is critical to ensure that effective research is accomplished and that research results are appropriately transitioned into operational systems and processes.

11.3 Transition of Research to Application

NOAA is committed to maximizing the value of its research and ensuring its research transitions into products and services that improve the quality of people's lives and those of future generations.

NOAA has taken the necessary steps to improve and streamline its process for transferring research into applications. NOAA has adopted a "Transition of Research to Application" policy and implementation procedures, which have established a consistent process within NOAA for identifying mature research and for accelerating the rate at which this research transitions into applications. A mechanism recognized in the policy to facilitate these transitions is the test environment, or test bed. Test beds offer the research community settings to work directly with NOAA's operational elements through established testing and evaluation protocols. The protocols provide clearly defined goals and decision points for cost-effective and rapid transition of new research and technologies into routine operations. Examples of test environments across NOAA were included in the agency's 5-year Research Plan for FY2005-2009 and are evident in chapters 6-10 of this edition of the Plan. Test environments are proving their utility in serving the research and operational communities and will remain an important means for NOAA to link them better.

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Execution of NOAA's streamlined transition process ensures the strategic partnership between the research and operations/applications communities. This strategic partnership focuses on delivering the application of emerging science and technology to end-users and fosters:

- Early communication and coordination between the research and operations/applications communities, establishing a coordinated development process dedicated to final application of new science and technology and including thorough consideration of possible applications.
- Joint investment and execution plans.
- Thorough consideration of common/compatible IT architectures ensuring streamlined, cost-effective transfer of new science and technology from research to applications.

Some successful examples of the transfer of research into applications over the past several years include:

- **The Deep Ocean Assessment and Reporting of Tsunami (DART) Buoys**
  The DART buoys fill an important national role in reducing loss of life and property in U.S. coastal communities and in the elimination of false alarms which result in high economic costs for unnecessary evacuations. The cancellation of a tsunami warning for Hawaii in November 2003 saved Hawaii $68M in Evacuation Costs. This piece of NOAA research clearly has had an economic and social impact for both warnings and cancelled warnings.

- **Great Lakes Operational Forecast System**
  NOAA research led to the development of an operational coastal forecasting system for the Great Lakes that provides lake carriers, mariners, port managers, emergency response teams, and recreational boaters with present and future conditions of water levels, wave heights, water currents, and water temperatures. The completion of this system is a key milestone in NOAA's continuing efforts to develop and implement sophisticated prediction products and services to support our nation's maritime commerce, to increase the safety for human use of the nation's coasts, and to aid in spill recovery. The Great Lakes Forecasting System uses information generated by a three-dimensional hydrodynamic model that relies on real-time observation to make forecasts that include data plots and animated maps.

- **The WSR-88D or NEXRAD Doppler Radar Network**
  NOAA research led to the acquisition and deployment of the WSR-88D Doppler radar network. The impacts of the Doppler radar network have been significant. Tornado warning lead times have increased from a few minutes to 12-13 minutes on average, and the probability of detection of tornados doubled to over 70%. This has subsequently resulted in the reduction of tornado related deaths by 45%.

- **Improved Hurricane Track Forecasts**
  NOAA research efforts have led to the significant reduction in the 3-5 day hurricane track forecast errors. As a result, NOAA's forecasts, warnings, and associated emergency response results in $3 B savings in typical hurricane seasons.

- **Air Quality Management**
  NOAA conducts air quality studies aimed at understanding the processes that lead to poor air quality, thereby providing information that underpins effective strategies to protect public health. Over 400 counties – more than half of the U.S. population - have an air quality that does not meet U.S. standards. In one such area, Houston/Galveston, NOAA conducted an air

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quality study in 2000. Results of the study allowed the state of Texas to reduce air pollution in the region while simultaneously saving the state an estimated $9B and 64,000 jobs over a ten-year period.

- **Forecasting Harmful Algal Bloom (HAB)**
  NOAA is the leading federal agency organizing HAB research. HAB outbreaks cause human illness and more than $75M in economic damages annually. NOAA research aims to understand HAB dynamics and to provide products to help mitigate the impacts of HABS. NOAA modeling expertise is assuring the successful development, validation, and demonstration of HAB forecasts. NOAA HAB research has and will continue to reduce the risk to human health and the environment.

NOAA has taken the initial steps needed to streamline and improve the process by which the organization transitions mature research into applications. NOAA will continue to improve the process and rate at which it transitions its research into products and services for our stakeholders.

11.4 Evaluating Research and Ensuring Success

One final key to keeping NOAA's research honed to deliver our mission outcomes is continual, rigorous, and consistent evaluation. NOAA evaluates its research progress and its impact on NOAA capabilities by linking research activities to the needs of its programs and operational units, and by ensuring the outcomes benefit both the organization and society.

In this plan, NOAA identifies a series of research milestones linked to strategic performance objectives across the mission goals. Clearly identifying the scientific research components required to attain outcomes is a critical first step in tracking the progress and articulating the success of NOAA's research. Although NOAA is a mission driven agency with projects tuned to delivering forecasts, warnings, environmental information and assessments, clearly identifying the scientific research foundations that make these services possible allows us to ensure a continued capability to deliver valuable, high quality, relevant scientific environmental information to the nation. Linking these research milestones from strategic planning through to tactical execution in a consistent manner across the full NOAA research enterprise provides a mechanism to track and measure the progress of our science. Research at the lab or program level must be traceable through research milestones to research areas that contribute to overall outcomes. On the other hand, NOAA management will encourage initiating high-risk projects that have the potential to dramatically transform NOAA research and how users use NOAA science and technology to address critical environmental and socioeconomic issues. These projects will be evaluated and monitored to ensure they continue to show potential or be terminated. NOAA annually reviews its research implementation plans, checking for consistency with this research plan and other strategic plans, and can refine research activities to respond to emerging science drivers. Near term priority research milestones are articulated in annual operating plans which cut across NOAA Line Offices and programs.

A hierarchy of mechanisms, from the earliest planning stage through implementation, ensures the relevance and excellence of NOAA research. In the planning and programming phase of PPBES, all proposed research is analyzed for its significance to addressing known requirements, compared against competing alternatives, examined for its performance characteristics, and its cost compared to the expected outcome. Although risk is a part of this analysis process, NOAA acknowledges that not all research will be successful and consciously chooses to invest a portion of its portfolio in transformational, high-risk research. In the second phase, when research funds

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are executed, a significant portion of the funds are awarded both externally and internally through a number of competitive proposal processes. Finally, as a continually learning organization, NOAA exercises a system of external reviews to ensure all levels of its research organization are evaluated at least once every 5 years. Peer reviews examine the progress of NOAA labs, offices, and programs in meeting its goals. A relevance review is used to judge the alignment of NOAA's research portfolio to its mission and priorities. A benchmark review evaluates the standing of NOAA's research nationally and internationally.

As a federal agency, NOAA is dedicated to providing value to the taxpaying public it serves. Clear identification of the research funding required and used to deliver NOAA's scientific milestones and missions allows NOAA to monitor and articulate the cost effectiveness of its programs. Through the PPBES system, research funding can be monitored across NOAA and linked to NOAA's science priorities and associated performance objectives. Throughout the year, NOAA offices provide routine progress reports tracking the adherence of research projects to incremental cost, schedule, and performance goals and allowing oversight of time sensitive outputs. On the longer term, success will be judged by the extent to which NOAA research answers overarching research questions like those posed at the outset of this Plan and, in so doing, brings tangible benefits to current and future generations of citizens.

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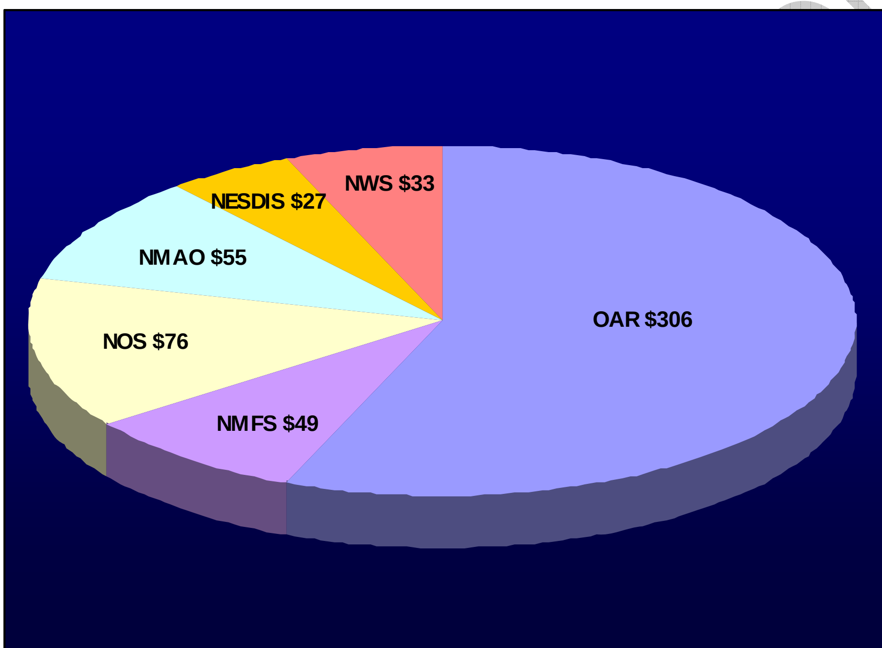
12. Appendix: NOAA's Research Infrastructure

The NOAA research infrastructure includes a system of federal laboratories and science centers and ship, aircraft, and other observing systems and platforms. This infrastructure is enhanced though assets provided by our external partners. Table 12.1 lists NOAA laboratories, centers, and cooperative institutes; a more detailed description of these institutions is included below.

Research planning throughout NOAA is based on mission goal relevance; however, because research is implemented and executed at the NOAA Line Office level, NOAA's infrastructure is characterized here according to NOAA Line Office assignment. Figure 12.1 indicates the research funding allotments to the line offices based on the enacted budget for FY 2006.



Based on FY 2006 enacted budget – in millions of dollars

Figure 12.1. Fiscal Year 2006 Funding for Research and Development in NOAA by Line Office. ***Note: Line Office values in the figure represent research and development strictly as defined by the NOAA Executive Council and reported to the National Science Foundation. They do not, therefore, necessarily reflect the entire scientific enterprise associated with each Line Office.***

Table 12.1. NOAA Laboratories, Centers, and Cooperative Institutes

Laboratories	Cooperative Institutes
National Environmental Satellite Data and Information Service	
Center for Satellite Applications and Research	Cooperative Institute for Climate Studies Cooperative Institute for Oceanographic Satellite Studies Cooperative Institute for Meteorological Satellite Studies Cooperative Remote Sensing Science and Technology Center
National Marine Fisheries Service	

Alaska Fisheries Science Center Northeast Fisheries Science Center Northwest Fisheries Science Center Pacific Islands Fisheries Science Center Southeast Fisheries Science Center Southwest Fisheries Science Center	Cooperative Institute for Marine Resources Studies Cooperative Marine Education and Research Program
National Ocean Service	
Center for Coastal Fisheries and Habitat Research Center for Coastal Monitoring and Assessment Center for Environmental Health and Biomolecular Research Ocean Systems Test and Evaluation Program Center for Sponsored Coastal Ocean Research Coast Survey Development Laboratory Hollings Marine Laboratory National Geodetic Survey Geosciences Research Division National Geodetic Survey Remote Sensing Research Group	
National Weather Service	
Environmental Modeling Center Meteorological Development Laboratory Office of Hydrological Development's Hydrology Laboratory Space Environment Center	
Office of Oceanic and Atmospheric Research	
Air Resources Laboratory Atlantic Oceanographic and Meteorological Laboratory Earth System Research Laboratory Geophysical Fluid Dynamics Laboratory Great Lakes Environmental Research Laboratory National Severe Storms Laboratory Pacific Marine Environmental Laboratory	Cooperative Institute for Arctic Research Cooperative Institute for Climate and Ocean Research Cooperative Institute for Climate Applications and Research Cooperative Institute for Climate Sciences Cooperative Institute for Limnology and Ecosystems Research Cooperative Institute for Marine and Atmospheric Studies Cooperative Institute for Mesoscale Meteorological Studies Cooperative Institute for Research in the Atmosphere Cooperative Institute for Research in Environmental Sciences Joint Institute for Marine and Atmospheric Research Joint Institute for Marine Observations Joint Institute for the Study of the Atmosphere and Ocean Northern Gulf Institute

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12.1 NOAA Laboratories and Centers

Accomplishing NOAA's missions requires a solid underpinning in atmospheric sciences, limnology, oceanography, chemistry, biology, mathematics, and space physics. NOAA's ability to meet our mission goals can only be as good as the state of knowledge in these scientific disciplines. Our laboratories and science centers conduct leading-edge fundamental and applied research on Earth's chemical, physical, and biological systems; this research leads to direct improvements in NOAA's ability to succeed in our mission.

12.1.1 Oceanic and Atmospheric Research (OAR) Laboratories

Air Resources Laboratory (ARL)

ARL conducts research on processes that relate to air quality and climate, concentrating on the transport, dispersion, transformation, and removal of trace gases and aerosols, their climatic and ecological influences, and exchange between the atmosphere and biological and non-biological surfaces.

Atlantic Oceanographic and Meteorological Laboratory (AOML)

AOML conducts research in physical oceanography, tropical meteorology, atmospheric and oceanic biogeochemistry, and acoustics in the world ocean with a focus on the Atlantic Ocean, Caribbean, and South Florida. AOML research seeks: to understand the physical characteristics and processes in the ocean and the atmosphere, both separately and as a coupled system, and their implications upon climate, biogeochemistry, ecosystems and tropical storms; and, to contribute to both seasonal to interannual climate forecasts and decadal to centennial climate predictions. AOML is a main partner in the development of a sustained Ocean Observing System for Climate to support NOAA mission requirements and a center for hurricane intensification research.

Earth System Research Laboratory (ESRL)

ESRL was formed October 1, 2005 as part of a reorganization and consolidation of six NOAA research entities in Boulder, Colorado, including the former Aeronomy Laboratory, Air Resources Laboratory (Surface Radiation Research Branch), Climate Diagnostics Center, Climate Monitoring and Diagnostics Laboratory, Environmental Technology Laboratory, and Forecast Systems Laboratory. The Earth System Research Laboratory's mission is to observe and understand the Earth system and to develop products through a commitment to research that will advance NOAA's environmental information and services on global-to-local scales. The work at the Earth System Research Laboratory includes global monitoring of gases and particles that affect climate, the ozone layer and air quality, understanding the roles of gases and particles that contribute to climate change, providing climate information related to water management decisions, improving weather prediction, understanding the recovery of the stratospheric ozone layer, and developing air quality forecast models.

Geophysical Fluid Dynamics Laboratory (GFDL)

GFDL conducts comprehensive long-term research fundamental to NOAA's mission of understanding climate variability and change. The goal of this research is to expand the scientific understanding and modeling of the physical processes that govern the behavior of the atmosphere and the oceans as complex fluid systems.

Great Lakes Environmental Research Laboratory (GLERL)

GLERL conducts research and provides scientific leadership to understand, observe, assess, and predict the status and changes of Great Lakes and coastal marine ecosystems to educate and advise stakeholders of optimal management strategies. GLERL houses a multidisciplinary scientific core focusing on research that leads ecosystem forecasts on physical hazards, water quality and quantity, human health, invasive species, and fish recruitment and productivity. It houses NOAA's National Invasive Species Center and the NOAA Center of Excellence for Great Lakes and Human Health.

National Severe Storms Laboratory (NSSL)

NSSL investigates all aspects of severe weather. Headquartered in Norman, OK, and in partnership with the NWS, NSSL is dedicated to improving severe weather warnings and forecasts in order to save lives and reduce property damage.

Pacific Marine Environmental Laboratory (PMEL)

PMEL carries out interdisciplinary investigations in oceanography and atmospheric science. Results from PMEL research activities contribute to seasonal-to-interannual climate forecasts,

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assessing and predicting decadal to centennial climate change, advancing short-term warning and forecast services, developing improved tsunami forecast capabilities, and building sustainable fisheries.

12.1.2 National Marine Fisheries Service (NMFS) Science Centers

Alaska Fisheries Science Center (AFSC)

AFSC is responsible for research in the marine waters and rivers of Alaska. The AFSC develops and manages scientific data and provides technical advice to the North Pacific Fishery Management Council, the NMFS Alaska Regional Office, U.S. representatives participating in international fishery negotiations, and the fishing industry and its constituents. The AFSC also conducts research on marine mammals worldwide, primarily in coastal California, Oregon, Washington and Alaska. This work includes stock assessments, life history determinations, and status and trends. Information is provided to various U.S. governmental and international organizations to assist in developing rational and appropriate management regimes for marine resources under NOAA's jurisdiction.

Northeast Fisheries Science Center (NEFSC)

NEFSC manages a multidisciplinary program of basic and applied research to better understand living marine resources of the Northeast Continental Shelf from the Gulf of Maine to Cape Hatteras. The NEFSC also describes and provides to management authorities, industry, and the public, options for the conservation and utilization of living marine resources.

Northwest Fisheries Science Center (NWFSC)

NWFSC conducts multidisciplinary research to provide fisheries management information and technical advice. Such information supports national NMFS programs, responds to the needs of the Pacific Fishery Management Council, and supports other constituencies along the U.S. West Coast.

Southeast Fisheries Science Center (SEFSC)

SEFSC conducts research in the southeastern United States, as well as Puerto Rico and the U.S. Virgin Islands. SEFSC develops scientific information required for fishery resource conservation, habitat conservation, and protection of marine mammals and endangered species. The SEFSC also conducts impact analyses and environmental assessments for international negotiations and for the South Atlantic, Gulf of Mexico, and Caribbean Fishery Management Councils.

Southwest Fisheries Science Center (SWFSC)

The Southwest Fisheries Science Center is the research arm of NOAA's National Marine Fisheries Service in the Southwest Region. Center scientists conduct marine biological, economic and oceanographic research, observations and monitoring on living marine resources and their environment throughout the Pacific Ocean and in the Southern Ocean off Antarctica. The ultimate purpose of these scientific efforts is for the conservation and management of marine and anadromous fish, marine mammal, sea turtle and other marine life populations to ensure that they remain at sustainable and healthy levels.

Pacific Islands Fisheries Science Center (PIFSC)

PIFSC conducts research on fisheries, coral reefs, protected species and the oceanographic and ecosystem processes that support them. PIFSC conducts biological, ecological, and socio-economic

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research in support of fishery management plans and protected species recovery plans. Research and analysis of the resulting fisheries data support fisheries policy and management; protected species efforts examine the status and problems affecting the populations of the Hawaiian monk seal and the sea turtles. PIFSC activities support the Western Pacific Regional Fishery Management Council, the NMFS Pacific Islands Regional Office, and international commissions on Pacific tuna.

National Systematics Laboratory

The National Systematics Laboratory is administered by the Northeast Fisheries Science Center, but serves as the taxonomic research arm of NOAA Fisheries as a whole. The Laboratory describes and names new species, and revises existing descriptions and names based on new information, of fishes, squids, crustaceans, and corals of economic or ecological importance to the United States.

National Seafood Inspection Laboratory (NSIL)

NSIL provides analytical laboratory, data management, Regulatory Compliance Risk Analysis, and Information Transfer expertise to meet the Office of Sustainable Fisheries (OSF) fishery management and seafood safety responsibilities. NSIL adapted its food safety risk analysis expertise to support specific fishery management and data collection programs of the OSF in the headquarters of the National Marine Fisheries Service.

12.1.3 National Environmental Satellite, Data, and Information Service (NESDIS) Center

Center for Satellite Applications and Research (STAR)

STAR is the science arm of NESDIS. The mission of STAR is to create satellite-based observations of the land, atmosphere, and ocean, and transfer them from scientific research and development into NOAA's routine operations. STAR is a leader in planning future satellite observing systems to enhance the nation's ability to remotely monitor the environment. STAR also calibrates the Earth-observing instruments of all NOAA satellites.

12.1.4 National Ocean Service (NOS) Laboratories and Centers

Center for Coastal Fisheries and Habitat Research (CCFHR)

CCFHR is jointly sponsored by the NOS and NMFS. The CCFHR conducts laboratory and field research on estuarine processes, the biological productivity of near-shore and ocean ecosystems, the dynamics of coastal and reef fishery resources, and the effects of human influences on resource productivity.

Center for Coastal Monitoring and Assessment (CCMA)

CCMA assesses and forecasts coastal and marine ecosystem conditions through research and monitoring. CCMA provides the best available scientific information for resource managers and researchers, as well as technical advice and data access. CCMA addresses pollution, land and resource use, invasive species, climate change, and extreme events.

Center for Coastal Environmental Health and Biomolecular Research (CCEHBR)

CCEHBR conducts research related to coastal ecosystem health, environmental quality, and public health. Chemical, biomolecular, microbiological, and histological research is conducted to

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describe, evaluate, and predict significant factors and outcomes of influences on marine and estuarine habitats. The Cooperative Oxford Laboratory in Oxford, MD, is part of CCEHBR.

Ocean Systems Test and Evaluation Program (OSTEP)

The Center for Operational Oceanographic Products and Services' OSTEP introduces new and improved oceanographic and marine meteorological sensors and systems to improve quality, responsiveness, and value of individual sensors or integrated sensor systems. In addition to the testing, evaluation, and integrating phases, OSTEP performs continuous research and awareness of technology offerings and their application to navigation safety.

Center for Sponsored Coastal Ocean Research (CSCOR)

CSCOR/COP is a federal-academic partnership to develop predictive capabilities for managing coastal ecosystems. High-priority research and interagency initiatives support quality science relevant to coastal policy decisions including issues directly supporting NOAA's overall mission.

Coast Survey Development Laboratory (CSDL)

CSDL explores, develops, and transitions emerging cartographic, hydrographic, and oceanographic technologies and techniques to provide products and services to Coast Survey, NOS, and NOAA partners and customers in the coastal community. These products support safe and efficient marine navigation and a sustainable coastal environment. CSDL consists of three components: Cartographic and Geospatial Technology Programs (CGTP), Hydrographic Systems and Technology Programs (HSTP), and Marine Modeling and Analysis Programs (MMAP).

Hollings Marine Laboratory (HML)

HML is a multi-institutional, inter-disciplinary institution providing science and biotechnology applications to sustain, protect, and restore coastal ecosystems, emphasizing linkages between environmental and human health.

National Geodetic Survey (NGS) Geosciences Research Division

The NGS Geosciences Research Division performs fundamental research in applications of GPS technology to Earth science and in development of gravity measurement systems.

National Geodetic Survey (NGS) Remote Sensing Research Division

The NGS Remote Sensing Research Group conducts research and development in emerging remote sensing technologies, including platforms, sensors, and processing and analysis hardware and software, with the goal of increasing the quality, quantity, and timeliness of information available for Integrated Ocean and Coastal Mapping (IOCM).

12.1.5 National Weather Service (NWS) Laboratories and Centers

National Centers for Environmental Prediction (NCEP)

NCEP delivers national and global weather, water, climate, and space weather guidance, forecasts, warnings, and analyses to a broad range of users and partners. These products and services respond to user needs to protect life and property, enhance the nation's economy, and support the nation's growing need for environmental information. In developing its products and services, NCEP's constituent Centers undertake and/or support the research needed to maintain its ranking as a world leader in operational environmental prediction.

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Meteorological Development Laboratory (MDL)

MDL develops and implements scientific techniques into NWS Operations. MDL furnishes a full spectrum of forecast guidance, provides interactive tools for decision assistance and forecast preparation, and conducts comprehensive evaluations of NWS Products.

Office of Hydrological Development's Hydrology Laboratory (OHD)

OHD enhances NWS products by infusing new hydrologic science, developing hydrologic, hydraulic and hydrometeorologic techniques for operational use, managing hydrologic development by NWS field offices, and providing advanced hydrologic products to meet needs identified by NWS customers. OHD also performs studies to update precipitation frequency climate normals.

12.2 Cooperative Institutes

NOAA's Cooperative Institutes are academic institutions that collaborate in a large portion of NOAA's research and play a vital role in broadening NOAA's ability to provide the expanding array of environmental assessment and predictions required to address the nation's forecasting needs.

Because many Cooperative Institutes are collocated with NOAA research laboratories, there is a strong, long-term collaboration between scientists in the laboratories and in the university. Cooperative Institutes not collocated with a NOAA laboratory often serve diverse research communities and research programs throughout NOAA.

12.2.1 OAR Cooperative Institutes

Cooperative Institute for Arctic Research (CIFAR)

CIFAR is a cooperative institute with the University of Alaska. CIFAR conducts research on a variety of issues critical to the Arctic and focus on fisheries oceanography; hydrographic studies; sea-ice dynamics; atmospheric research; climate dynamics and variability; tsunami research and prediction, assessment, and monitoring; and numerical modeling.

Cooperative Institute for Climate Applications and Research (CICAR)

CICAR is a cooperative institute with Columbia University. Research themes include modeling, prediction, and assessment of climate variability and change; development, collection, analysis, and archiving of instrumental and paleoclimate data; and development of climate variability and change prediction and assessment to provide information for decision makers.

Cooperative Institute for Climate and Ocean Research (CICOR)

CICOR is a cooperative institute with the Woods Hole Oceanographic Institution. The research activities of CICOR are organized around the coastal ocean and near-shore processes, the ocean's participation in climate and climate variability, and marine ecosystem processes analysis.

Cooperative Institute for Climate Sciences (CICS)

CICS is a cooperative institute with Princeton University. Research will support Earth system model development, climate product generation, and development of models to study regional/global climate variability and change, oceanic and terrestrial carbon cycles, and other processes important in projections of future climate variability and change.

Cooperative Institute for Limnology and Ecosystems Research (CILER)

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CILER is a regional cooperative institute with the University of Michigan, with formal links to Michigan State University and universities throughout the Great Lakes Region. Primary research focuses on climate and large-lake dynamics, coastal and nearshore processes, large-lake ecosystem structure and function, remote sensing of large lake and coastal ocean dynamics, and marine environmental engineering.

Cooperative Institute for Marine and Atmospheric Studies (CIMAS)

CIMAS is a cooperative institute with the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences that works closely with AOML. Research is conducted within five themes—Climate Variability, Fisheries Dynamics, Ocean Observing Systems, Air-sea Interaction, and Coastal Ocean Ecosystem Processes—all in collaboration with NMFS. The latter theme is also in collaboration with OAR.

Cooperative Institute for Mesoscale Meteorological Studies (CIMMS)

CIMMS is a cooperative institute with the University of Oklahoma. Research includes basic convective and mesoscale forecast improvements, climatic effects of controls on mesoscale processes, socioeconomic effects of mesoscale weather systems, and regional scale climate variations. CIMMS collaborates with the NSSL and supports the NWS modernization efforts.

Cooperative Institute for Research in the Atmosphere (CIRA)

CIRA is a cooperative institute with Colorado State University. CIRA conducts research involving global and regional climate, local and mesoscale area weather forecasting and evaluation, applied cloud physics, applications of satellite observations, air quality and visibility, societal and economic impacts, numerical modeling, and education, training, and outreach.

Cooperative Institute for Research in Environmental Sciences (CIRES)

CIRES is a cooperative institute with the University of Colorado. CIRES conducts research in environmental chemistry and biology, atmospheric and climate dynamics, cryospheric and polar processes, and the solar-terrestrial environment.

Joint Institute for Marine and Atmospheric Research (JIMAR)

JIMAR is a cooperative institute with the University of Hawaii. Research includes equatorial oceanography, climate research, tsunamis, fisheries oceanography, tropical meteorology, and coastal research. JIMAR works closely with the Pacific Islands Region and Southwest Region of NMFS and NWS, as well as the Coastal Services Center in Honolulu.

Joint Institute for Marine Observations (JIMO)

JIMO is a cooperative institute with the University of California's Scripps Institution of Oceanography. State-of-the-art observation capabilities—such as platforms (surface, subsea, and air/space), sensors, and systems architecture—are utilized to fill pressing research needs. Of particular interest at JIMO are coupled ocean-atmosphere climate research, oceanography, marine geology and geophysics, and ocean technology.

Joint Institute for the Study of the Atmosphere and Ocean (JISAO)

JISAO is a cooperative institute with the University of Washington. JISAO complements the research at PMEL in climate variability, environmental chemistry, estuarine processes, tsunami forecast modeling, and interannual variability of fisheries recruitment.

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Northern Gulf Institute (NGI)

NOAA recently formed a cooperative institute in the northern Gulf of Mexico with a consortium of universities, led by Mississippi State University and including the University of Southern Mississippi, Louisiana State University, Dauphin Island Sea Lab, and Florida State University. The Northern Gulf Institute will conduct research under four scientific themes: 1) climate change and climate variability effects on regional ecosystems; 2) coastal hazards; 3) ecosystem management; and 4) geospatial data integration and visualization. This research will also support the national Integrated Ocean Observing System through the Gulf of Mexico Coastal Ocean Observing System (GCOOS).

12.2.2 NMFS Cooperative Institutes

Cooperative Institute for Marine Resources Studies (CIMRS)

The CIMRS is a cooperative institute at Oregon State University that brings together scientists from NOAA's NW Fisheries Science Center, the Pacific Marine Environmental Laboratory, and Oregon State University to work on problems of mutual interest relating to the living and non-living components of the marine environment and their interrelationships. CIMRS research staff is currently involved in scientific efforts that parallel NOAA's program objectives in the areas of geological/chemical and fisheries oceanography.

Cooperative Marine Education and Research (CMER) Program

The CMER program is a partnership between NOAA and five academic institutions: the University of Massachusetts, the University of Rhode Island, Rutgers University, the Virginia Institute of Marine Science and Hampton University. This cooperative program addresses mission-related research problems identified by the agency and facilitates the training of marine scientists and strives to help the nation meet the challenges posed by issues of resource management in the marine environment.

12.2.3 NESDIS Cooperative Institutes

Cooperative Institute for Climate Studies (CICS)

CICS is a cooperative institute with the University of Maryland. CICS was established to foster collaborative research in studies of satellite climatology, climate diagnostics, modeling, and prediction.

Cooperative Institute for Meteorological Satellite Studies (CIMSS)

CIMSS is a cooperative institute with the University of Wisconsin-Madison. CIMSS conducts research using passive remote-sensing systems for meteorological and surface-based applications and develops techniques for using geostationary weather satellite thermal radiation observations to improve severe storm forecasts.

Cooperative Institute for Oceanographic Satellite Studies (CIOSS)

CIOSS is a cooperative institute with Oregon State University. CIOSS develops, improves, and evaluates methods of ocean remote sensing and ocean-atmosphere modeling. Specific applications include basic research into ocean and atmosphere dynamics, contributions to ocean observing/modeling systems, and evaluation of plans for future systems and models.

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Cooperative Remote Sensing Science and Technology Center (CREST)

CREST is a Cooperative Center composed of a consortium lead by the City College of the City of University of New York. The other members of the consortium are: Bronx Community College, Bowie State University, Columbia University, Hampton University, Lehman College, University of Maryland, and the University of Puerto Rico. Research is conducted on atmospheric remote sensing and air quality monitoring; estuarine, coastal, and marine remote sensing and water quality monitoring; and remote sensing applications for environmental assessment and forecasting.

12.3 Grant Programs

12.3.1 The National Sea Grant College Program

The National Sea Grant Program works closely with the 30 state Sea Grant programs located in every coastal and Great Lakes state and Puerto Rico. Sea Grant provides a stable national infrastructure of programs serving as the core of a dynamic, national university-based network of over 300 institutions involving more than 3,000 scientists, engineers, educators, students and outreach experts. This network works on a variety of topics vital to human and environmental health—topics such as water quality, coastal hazards, and biotechnology. Through their research, education and outreach activities, Sea Grant has helped position the United States as the world leader in marine research and the sustainable development of coastal resources. Sea Grant activities exist at the nexus of local, state, national and sometimes international interests. In this way, local needs receive national attention, and national commitments are fulfilled at the local level.

12.3.2 NOAA's Office of Ocean Exploration and Research (OER)

The NOAA Office of Ocean Exploration and Research is comprised of the Ocean Exploration and National Undersea Research Programs. A final plan for their merger will be available in Fall 2007 at the conclusion of a process that includes input from NOAA programs as well as the external community.

Ocean Exploration

Through its annual grant solicitation, the NOAA Office of Ocean Exploration and Research sponsors exploratory expeditions, projects and related field campaigns for the purpose of discovery and new understanding at our ocean and Great Lakes frontiers. These explorations are anticipated to revolutionize our knowledge baselines by exploring, characterizing and mapping, at new and/or higher than existing scales, the ocean's living and non-living resources and its physical, chemical, biological and archaeological characteristics. Data and observations resulting from the explorations will result in new discoveries, new insight, new knowledge and new frontiers and will likely lead to the revision of existing paradigms or the formulation of new paradigms in the oceans poorly known and unknown regions.

NOAA's Undersea Research Program (NURP)

The NURP component of OER provides NOAA with the unique ability to access the undersea environment either directly with submersibles and technical diving, or virtually using robots and seafloor observatories. NURP provides scientists with the tools and expertise they need to investigate the undersea environment, including submersibles, remotely operated vehicles,

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autonomous underwater vehicles, mixed gas diving gear, underwater laboratories and observatories, and other cutting edge technologies. NURP provides extramural grants to both the federal and non-federal research community through regional centers and the National Institute of Undersea Science and Technology, while assisting scientists in acquiring data and observations that provide the information necessary to address a variety of NOAA's priority goals.

12.3.3 Geodetic Science and Applied Research (GSAR) Program

The objective of the GSAR Program is to improve positioning operations and services in support of transportation and commerce on a national basis.

12.3.4 Educational Partnership Program (EPP)

The EPP Cooperative Science Centers reside at minority serving institutions (MSIs) to advance scientific research and to provide training to students in coursework directly related to NOAA's mission.

12.3.5 NOAA's Collaborative Science, Technology, and Applied Research (CSTAR) Program

The CSTAR Program represents an NOAA National Weather Service effort to create a cost-effective transition from basic and applied research to operations and services through collaborative research between operational forecasters and academic institutions which have expertise in the environmental sciences. These activities engage researchers and students in applied research of interest to the operational hydrometeorological community and improve the accuracy of forecasts and warnings of environmental hazards by applying scientific knowledge and information to operational products and services.

12.3.6 NOAA Fisheries Service Cooperative Research Program

NOAA Fisheries Service Cooperative Research Program provides a means for commercial and recreational fishermen to become involved in the collection of fundamental fisheries information to support the development and evaluation of management options. In cooperative research, industry and other stakeholders can partner with NOAA and university scientists, in all phases of the program, including survey/ statistical design, conducting of research, analysis of results, and communication of results.

12.4 Fleet Services

NOAA Marine and Aviation Operations (NMAO) operates a wide variety of specialized aircraft and ships to complete NOAA's environmental and scientific missions. NOAA's ship fleet provides hydrographic survey, oceanographic and atmospheric research, and fisheries research vessels to support NOAA's research activities. NOAA also operates a fleet of fixed-wing and aircraft that collect the environmental and geographic data essential to NOAA hurricane and other weather and atmospheric research; provide aerial support for remote sensing projects; conduct aerial surveys for hydrologic research to help predict flooding potential from snow melt;, and provide support to NOAA's fishery and protected species research. To complement NOAA's research fleet, NOAA's ship and aircraft support needs are met through contracts for ship and aircraft time with other sources, such as the private sector and the university fleet.

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